GIS applications in wildland/urban interface fire management and planning in Missoula County MT

Kelly R. Close
The University of Montana
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GIS APPLICATIONS IN WILDLAND/URBAN INTERFACE

FIRE MANAGEMENT AND PLANNING IN

MISSOULA COUNTY, MT

by

Kelly R. Close

B.S., The University of California, Davis, 1980

presented in partial fulfillment of the requirements

for the degree of

Master of Science

The University of Montana

1995

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6-17-94

Date
The wildland/urban interface is a term used to describe areas where structures, primarily residential, intermingle with or border on areas with high wildfire danger. It presents a great problem for protection of lives, property, and natural resources. Divergent fire suppression capabilities are required to deal simultaneously with structural fires and wildland fires; wildland firefighters are typically not trained in structure fire protection, and structural fire protection agencies can quickly become overwhelmed on a large wildfire.

The wildland/urban interface is an ever-increasing problem in Missoula County (Montana) due to the large number of homes located in wildland areas, and has been compounded by the recent surge of residential growth throughout the county. Current planning measures are insufficient to adequately address needs for hazard mitigation, land use planning, and fire protection and prevention. All too often, even the best of efforts have resulted in little more than incremental changes in the status quo.

The development of a comprehensive geographical information base is vital for effective fire prevention, pre-suppression, suppression, and operations planning. This is due to the complexity of fire management and resource protection strategies in the interface¹, and the unique and diverse needs of fire protection personnel in each agency at numerous levels of planning.

This project demonstrates the use of a geographic information system (GIS) as a baseline for pre-suppression and prevention planning in interface areas of Missoula County, exploring the spatial analysis of numerous interrelated factors important to the interface. The map and database components of the GIS are used to quantify hazards, more accurately define and characterize “risk” associated with interface areas, and determine needs for fire hazard mitigation near structures (“defensible space”). In addition, the GIS is used to assess existing fire protection systems and inter-jurisdictional issues.

¹Unless otherwise indicated, the term “interface” will be used throughout this thesis as a generic term for the wildland/urban interface.
PREFACE

Somewhere between the inception of this project in early 1990 and its eventual conclusion at the end of 1995, this project took on a life of its own. What started as a seemingly straightforward, logical use of GIS technology turned into a living, breathing creature that would both reward me with satisfaction and taunt me with hurdles, glitches, and headaches. Once I was fully immersed in data, technology and software, countless fire management and emergency services uses for the GIS began materializing. The real challenge then became limiting the scope of the project to a handful of applications, keeping a strong focus on the analyses, and keeping myself motivated to push forward.

The latter was the toughest. Within two months of beginning the project, I went to work full-time for the Fire Management Bureau of the Montana Department of State Lands. As welcome as this opportunity was, it also meant that virtually all the work I would do for this study would be outside of a full-time job. Not impossible, but not exactly conducive to having any kind of real life either. So with the completion of this document comes a great deal of satisfaction, a feeling of accomplishment, and untold relief on the part of my Graduate Committee. And a chance to catch my breath and regain control of my life.

There are several groups of people that made this project a reality — (1) those who contributed time, expertise, and data, (2) those who contributed moral support, and (3) those who contributed financial support. None of these groups are entirely mutually exclusive of any of the others, and I would not have gotten as far as I did without their help. This included people from every fire protection agency in Missoula County, and the Missoula city and county governments. I am very grateful for their help, because without it, much of this study would not have been possible. Many are referenced where appropriate in this thesis. In the meantime, there are some people I would like to recognize up front for playing a key role in getting the project going, and getting me through this. They are listed (roughly) in alphabetical order.

iii
Jon Agner -- for being a substantial influence, and frequent associate in local fire protection, prevention, and planning projects in Missoula County. Not to mention much-appreciated moral support.

Blackfoot Forest Protective Association (BFPA) -- for providing the "seed money" to get this project off the ground.


Jeannie Franz (Univ. of Montana Graduate School) -- for being incredibly patient while I finished the last steps of the "thesis marathon." Not to mention always very helpful and friendly.

Jack Lozenski -- for providing information and maps of most of the post-1889 fire history for Missoula County.

Marge Lubinski -- for providing me access to all the USFS aerial photos for Missoula County, many of which are shown in this thesis, and use of the USFS "B" series maps.

Katie MacMillen -- for hounding me mercilessly about my writing style and providing helpful, constructive criticisms.

Tom McIsaac -- for providing many of the photos from the Montana DSL that are shown in this thesis, and input and feedback on some of the graphics.

McIntire-Stennis Cooperative Research Service -- for providing additional funding that helped with hardware, software, and data acquisition necessary for this study.

Tim Murphy and "Honest Jack" Peters -- for support, encouragement, and being understanding about me sometimes "flexing" my work schedule to get this thing done.

Bill Summers -- for providing moral support, much-needed beer breaks, and constant encouragement.
Ron Wakimoto -- for enduring my “Master’s Marathon” and, being very patient. Ron’s tireless pursuit of truth, logic, and common sense in the tangled social, political, and scientific arenas of fire management have been a profound influence on my thinking. He has left me with faith that there really are people in the world who are driven by a desire to “do the right thing,” rather than by egos and hidden agendas.

Rohn Wood, Scott Purl, and Ken Wall -- for their technological wizardry, and patience with my rather large data files clogging up the GIS Lab system in the School of Forestry. I may never live down that reputation.

Hans Zuuring -- for much-appreciated help with the regression analysis of fire occurrence (Chapter 5).

My Committee (Ron Wakimoto, Hans Zuuring, and Mike Kupilik) -- for their constructive feedback, insight, and patience. And for seeing me through to a successful end!

My Family -- for always being there. They never had any doubts, even when I sometimes did. Five!
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>iii</td>
</tr>
<tr>
<td>PREFACE</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>viii</td>
</tr>
<tr>
<td>&quot;FIRE&quot;</td>
<td>xii</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Background of the Study</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Statement of the Problem</td>
<td>4</td>
</tr>
<tr>
<td>1.3 Objectives</td>
<td>6</td>
</tr>
<tr>
<td>1.4 Significance of the Study</td>
<td>7</td>
</tr>
<tr>
<td>1.5 Thesis Organization</td>
<td>8</td>
</tr>
<tr>
<td>2. BACKGROUND: FIRE, POLITICS AND GIS</td>
<td>11</td>
</tr>
<tr>
<td>2.1 The Wildland/Urban Interface Problem</td>
<td>11</td>
</tr>
<tr>
<td>2.2 Study Area Background</td>
<td>23</td>
</tr>
<tr>
<td>2.3 Geographic Information Systems (GIS)</td>
<td>51</td>
</tr>
<tr>
<td>3. METHODS</td>
<td>68</td>
</tr>
<tr>
<td>3.1 Study Area Boundaries</td>
<td>68</td>
</tr>
<tr>
<td>3.2 Dataset Organization</td>
<td>71</td>
</tr>
<tr>
<td>3.3 Software and Hardware</td>
<td>87</td>
</tr>
<tr>
<td>4. VARIABLES AND SOURCES OF VARIATION</td>
<td>88</td>
</tr>
<tr>
<td>4.1 Sources of Error</td>
<td>88</td>
</tr>
<tr>
<td>4.2 Constraints of the Analysis</td>
<td>94</td>
</tr>
<tr>
<td>5. ANALYSIS AND DISCUSSION</td>
<td>98</td>
</tr>
<tr>
<td>5.1 Hazard Analysis -- Fire Behavior Mapping</td>
<td>98</td>
</tr>
<tr>
<td>5.2 Defensible Space Analysis</td>
<td>117</td>
</tr>
<tr>
<td>5.3 Spatial Risk</td>
<td>134</td>
</tr>
<tr>
<td>5.4 Jurisdictional Issues and Protection Policies</td>
<td>153</td>
</tr>
<tr>
<td>6. SUMMARY AND CONCLUSIONS</td>
<td>160</td>
</tr>
</tbody>
</table>
REFERENCES

Appendices ........................................................................................................................................ 162
A. Glossary of Terms ...................................................................................................................... 163
B. Fire Protection Organizations in Missoula County ................................................................. 166
C. Excerpt from Fire Services In the Missoula Valley (Silverman, 1993) ................................. 167
D. 1994 Southwestern Montana Multi Agency Annual Operating Plan .................................... 174
E. Missoulian Articles Pertaining to the 1989 Rattlesnake Annexation ..................................... 181
F. Summary of Missoula County (MSLACO) Map Layers ....................................................... 183
G. Summary of Rattlesnake (RATTLE2) Map Layers ................................................................ 184
H. Legal Description of the Missoula County Boundary .............................................................. 185
I. USGS Digital Line Graph Files Used for Baseline Layers in MSLACO ................................. 186
J. Source of Local FSO Jurisdictional Boundary Data ............................................................... 187
K. IFSL Fuel Models Used in the Study ...................................................................................... 188
L. Missoula County Land Cover Classes .................................................................................... 191
M. Missoula County Land Cover Map ...................................................................................... 192

Literature Cited ................................................................................................................................ 193
# LIST OF TABLES

Tables are numbered according to the chapter and major section to which they refer (2.1.X), and then sequentially within each major section.

## CHAPTER 3

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.1</td>
<td>Map extents for RATTLE1, the initial map for the Rattlesnake Valley</td>
</tr>
<tr>
<td>3.1.2</td>
<td>Map extents for RATTLE2, the final working map for the Rattlesnake Valley</td>
</tr>
<tr>
<td>3.1.3</td>
<td>USGS 1:100,000 scale mylar maps used for constructing initial base map layers for MSLACO</td>
</tr>
<tr>
<td>3.1.4</td>
<td>USGS 1:24,000 scale maps used for RATTLE1 and RATTLE2 base layers</td>
</tr>
<tr>
<td>3.1.5</td>
<td>Description of road classifications used for all maps</td>
</tr>
<tr>
<td>3.2.1</td>
<td>USG DLG file coverages used for MSLACO map</td>
</tr>
<tr>
<td>3.2.2</td>
<td>USGS 1:250,000 scale DMA files used for the MSLACO digital elevation model</td>
</tr>
<tr>
<td>3.2.3</td>
<td>Classification of land ownership -- MSLACO</td>
</tr>
<tr>
<td>3.2.4</td>
<td>Sources of large fire history data, 1889 - 1991; fire perimeters and occurrence information</td>
</tr>
</tbody>
</table>

## CHAPTER 5

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1.1</td>
<td>Wildland dead fuel moisture timelag classes used for fire behavior prediction and fire danger rating</td>
</tr>
<tr>
<td>5.1.2</td>
<td>Weather inputs to the fire behavior prediction model; Missoula County</td>
</tr>
<tr>
<td>5.1.3</td>
<td>Fuel moisture inputs to the BEHAVE model for the Missoula County hazard analysis</td>
</tr>
<tr>
<td>5.1.4</td>
<td>Flame length, fireline intensity, and suppression resources that can be used on a fire</td>
</tr>
<tr>
<td>5.1.5</td>
<td>Flame length class and area represented, Pattee Canyon and LP Mill Fire scenarios</td>
</tr>
<tr>
<td>5.2.1</td>
<td>GIS input layers for the defensible space analysis</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Transformation of slope values by formula in proximity analysis</td>
</tr>
<tr>
<td>5.2.3</td>
<td>Comparison of defensible space recommendations from two different sources</td>
</tr>
<tr>
<td>5.3.1</td>
<td>Chi-square analysis of human-caused fire occurrences in relation to road proximity</td>
</tr>
<tr>
<td>5.3.2</td>
<td>Summary of Chi-square analysis for wildfire occurrence vs. road proximity and population density</td>
</tr>
<tr>
<td>5.3.3</td>
<td>Summary of human-caused fire occurrence data by road proximity corridor</td>
</tr>
<tr>
<td>5.3.4</td>
<td>Summary of human-caused fire occurrence data by population density</td>
</tr>
<tr>
<td>5.3.5</td>
<td>Summary of input data for the final regression analysis</td>
</tr>
<tr>
<td>5.4.1</td>
<td>Fire service organizations in Missoula County -- types and protection responsibilities</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

Figures are numbered according to the chapter and major section to which they refer (2.1.X), and then sequentially within each major section.

<table>
<thead>
<tr>
<th>Figure</th>
<th>CHAPTER 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1.1a</td>
<td>Example of fires with flame length less than 4 ft.</td>
</tr>
<tr>
<td>2.1.1b</td>
<td>Example of fires with flame length of greater than 8 ft.</td>
</tr>
<tr>
<td>2.1.2</td>
<td>Example of defensible space</td>
</tr>
<tr>
<td>2.1.3</td>
<td>Defensible space and a structure’s vulnerability</td>
</tr>
<tr>
<td>2.1.4</td>
<td>Percent of structures destroyed in wildfire vs. roof composition and vegetation clearance</td>
</tr>
<tr>
<td>2.1.5</td>
<td>Probability of loss related to clearance distance, type of construction, and soffit vent material</td>
</tr>
<tr>
<td>2.2.1</td>
<td>Oblique aerial photo of the Missoula Valley</td>
</tr>
<tr>
<td>2.2.1</td>
<td>Then and now... the Rattlesnake fire of 1919 and the LP Mill fire (newspaper headlines)</td>
</tr>
<tr>
<td>2.2.3</td>
<td>The Pattee Canyon Fire</td>
</tr>
<tr>
<td>2.2.4</td>
<td>Fire behavior in the Pattee Canyon Fire</td>
</tr>
<tr>
<td>2.2.5</td>
<td>Aftermath of the Pattee Canyon Fire</td>
</tr>
<tr>
<td>2.2.6</td>
<td>A &quot;Survivor&quot; of the Pattee Canyon Fire</td>
</tr>
<tr>
<td>2.2.7</td>
<td>GIS-generated perspective view of Missoula County</td>
</tr>
<tr>
<td>2.2.8</td>
<td>Land ownership map of Missoula County</td>
</tr>
<tr>
<td>2.2.9</td>
<td>&quot;What... Me Plan?” -- criticism of local officials over planning issues</td>
</tr>
<tr>
<td>2.2.10</td>
<td>Schematic map of Missoula County with photopoint locations</td>
</tr>
<tr>
<td>2.2.11</td>
<td>Aerial photo of the Houle Creek area north of Frenchtown</td>
</tr>
<tr>
<td>2.2.12</td>
<td>Typical fuels in the &quot;Frenchtown Face&quot; area</td>
</tr>
<tr>
<td>2.2.13</td>
<td>The Seeley Lake area, viewed from Double Arrow Lookout</td>
</tr>
<tr>
<td>2.2.14</td>
<td>Aerial photo of the Seeley Lake community</td>
</tr>
<tr>
<td>2.2.15</td>
<td>Aerial photo of the Double Arrow subdivision</td>
</tr>
<tr>
<td>2.2.16</td>
<td>Fuels and powerline corridor -- Double Arrow (Seeley Lake area)</td>
</tr>
<tr>
<td>2.2.17</td>
<td>The Petty Creek drainage, viewed from Martin Point</td>
</tr>
<tr>
<td>2.2.18</td>
<td>Aerial photo, upper Petty Creek drainage</td>
</tr>
<tr>
<td>2.2.19</td>
<td>The southwestern portion of the Ninemile Valley, viewed from Stark Mountain Lookout</td>
</tr>
<tr>
<td>2.2.20</td>
<td>Aerial photo showing residential development in the lower Ninemile Valley</td>
</tr>
<tr>
<td>2.2.21</td>
<td>Oblique aerial photo of the Grant Creek drainage</td>
</tr>
<tr>
<td>2.2.22</td>
<td>Colorado Gulch subdivision</td>
</tr>
<tr>
<td>2.2.23</td>
<td>The Rattlesnake Valley</td>
</tr>
<tr>
<td>2.2.24</td>
<td>Schematic map of the Rattlesnake Valley</td>
</tr>
<tr>
<td>2.2.25</td>
<td>The upper Rattlesnake Valley</td>
</tr>
<tr>
<td>2.2.26</td>
<td>Aerial photo of the upper Rattlesnake Valley</td>
</tr>
<tr>
<td>2.2.27</td>
<td>The Rattlesnake Creek Corridor</td>
</tr>
<tr>
<td>2.2.28</td>
<td>Madera Drive in the upper Rattlesnake Valley</td>
</tr>
<tr>
<td>2.2.29</td>
<td>GIS-generated perspective view of the Rattlesnake Valley showing fire history</td>
</tr>
<tr>
<td>2.3.1</td>
<td>Schematic drawing of GIS layers</td>
</tr>
</tbody>
</table>
2.3.2 The polygon overlay process ................................................................. 53
2.3.3 Defensible space recommendation -- MT DSL ................................................. 62
2.3.4 Defensible space recommendations for forested areas -- state of Colorado .... 63
2.3.5 Defensible space distance by slope direction and degree of slope ............ 63

CHAPTER 3

3.1.1 Location of the Missoula County Study Area ............................................. 69
3.1.2 Location of the Rattlesnake Valley study areas ........................................... 69
3.2.1 USGS DLG file coverages for the MSLACO map ........................................... 72

CHAPTER 5

5.1.1 Digital elevation model (DEM), Missoula County ...................................... 100
5.1.2 Slope map, Missoula County ...................................................................... 101
5.1.3 Aspect map, Missoula County ..................................................................... 102
5.1.4 IFSL fuel models, Missoula County .......................................................... 103
5.1.5 Area represented by each class for the classified DEM, slope, aspect, and IFSL fuel model layers in MSLACO .......................................................... 104
5.1.6 Fire behavior characteristics ("hauling") chart ............................................ 106
5.1.7 Fire behavior characteristics chart, logarithmic scale ............................... 107
5.1.8 Predicted flame length; Pattee Canyon scenario ........................................ 109
5.1.9 Predicted flame length, LP Mill scenario .................................................... 110
5.1.10 Rate of spread (ROS), Pattee Canyon weather conditions ....................... 111
5.1.11 Elevation effects on fine fuel moisture adjustments .................................. 112
5.1.12 Fine fuel moisture correction zones for weather measured at the Missoula County Airport ................................................................. 114
5.1.13 Hazard (flame length) map for all zones within +/- 1000 ft. of the weather monitoring site at the Missoula County Airport .............................................. 115
5.2.1 Schematic map of the Rattlesnake Valley showing roads and houses .......... 120
5.2.2 Rattlesnake Valley digital elevation model (DEM) ....................................... 121
5.2.3 Rattlesnake Valley fuel model classifications ............................................. 121
5.2.4 Rattlesnake Valley slope map ................................................................. 122
5.2.5 Rattlesnake Valley aspect map ............................................................... 122
5.2.6 Secondary weightings for defensible space "buffer" zones based on the position of a pixel in relation to a house's position on a slope ............................ 126
5.2.7 Predicted flame length in the Rattlesnake Valley (hypothetical conditions, no wind) .............................................................. 128
5.2.8 Predicted flame length in the Rattlesnake Valley (hypothetical conditions, 10 mph wind) .............................................................. 128
5.2.9 Unmodified proximity map of the Rattlesnake depicting 30- and 100-ft. distances from structures ......................................................... 130
5.2.10 "Defensible Space" map of the Rattlesnake depicting the primary and secondary vegetation clearance zones ..................................................... 130
5.2.11 Aerial photo of the upper Rattlesnake with an overlay of roads and houses .... 131
5.2.12 Primary and secondary fuel clearance zones for the upper Rattlesnake, per the defensible space analysis ................................................................. 131
<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2.13</td>
<td>Aerial oblique view of the upper Rattlesnake, looking to the southwest</td>
</tr>
<tr>
<td>5.2.14</td>
<td>Perspective view of the same area [4.2.13] showing the GIS-derived hazard classes</td>
</tr>
<tr>
<td>5.2.15</td>
<td>Perspective view of defensible space zones, upper Rattlesnake</td>
</tr>
<tr>
<td>5.2.16</td>
<td>Predicted fire behavior with defensible space</td>
</tr>
<tr>
<td>5.3.1</td>
<td>Human-caused fires, 1981 - 1990 (Missoula County)</td>
</tr>
<tr>
<td>5.3.2</td>
<td>Lightning-caused fires, 1981 - 1990 (Missoula County)</td>
</tr>
<tr>
<td>5.3.3</td>
<td>Human-caused fire occurrence per quarter-quarter section in Missoula County, from 1981 - 1990</td>
</tr>
<tr>
<td>5.3.4</td>
<td>Population density map of Missoula County, 1991 census</td>
</tr>
<tr>
<td>5.3.5</td>
<td>Proximity to highways, paved streets, and primary dirt/gravel roads</td>
</tr>
<tr>
<td>5.3.6</td>
<td>Human- and lightning-caused fire occurrence by road proximity class</td>
</tr>
<tr>
<td>5.3.7</td>
<td>Human- and lightning-caused fire occurrence by population density class</td>
</tr>
<tr>
<td>5.4.1</td>
<td>Fire service organization jurisdictional areas as of 7/92</td>
</tr>
<tr>
<td>5.4.2</td>
<td>Wildland agency jurisdictional areas as of 7/92</td>
</tr>
<tr>
<td>5.4.3</td>
<td>Overlay of fire service organization and wildland agency jurisdictional areas, Missoula Valley</td>
</tr>
<tr>
<td>5.4.4</td>
<td>Large fire history in the Missoula Valley, 1889 - 1991</td>
</tr>
<tr>
<td>5.4.5</td>
<td>Overlay of fire history in the Missoula Valley with fire protection jurisdictions</td>
</tr>
</tbody>
</table>
FIRE

A fire burns along the eastern rim of the mountains. We in the valley see it as a celestial prank, for in the summer haze the mountains themselves are lost, but as the night deepens the fire grows more golden and dense. On this calm ground the raw raging of burning winds that cuts the eyes and singes the hair is seen as a pencil-line of light moving southward. I know my son is there, has been for four days, moved in and out by helicopters with his squad of firefighters. By now, without sleep, they've gone beyond exhaustion. Some can't waken, some are crazed, a few go on - the oldest - working steadily. I know this from the stories he has told me of other famous fires from which he has returned as from a dream, his eyes glazed with seeing, his sense of time and place gone. He would raise his shaking right arm above his head, and with his palm open sweep it toward me again and again and speak without grammar, sometimes without words, of what had taken place. I knew it was true. Now in the cool of evening I catch a hint of the forest, of that taking of sudden breath that pines demand. It's on my skin, a light oil, a sweat born of some forgotten leaning into fire.

-PHILIP LEVINE

(from the New Yorker, 7/17/80)
CHAPTER 1.

INTRODUCTION

PERSISTENCE

"Nothing in the world can take the place of persistence. Talent will not; nothing is more common than unsuccessful men with talent. Genius will not; unrewarded genius is almost a proverb. Education will not; the world is full of educated derelicts. Persistence and determination alone are omnipotent."

-- Calvin Coolidge (original source unknown).

1.1 PROJECT BACKGROUND

The work presented in this document has been four years in the making. I began work on this project during the winter of 1990. The concept took form while I was finishing a GIS course in the School of Forestry, still grasping for a thesis research project. I had a strong interest in the wildland/urban interface issue, and a GIS study of the subject seemed like an ideal project. To my surprise, not much had been written in this area at that time.

Natural resources and related fields seemed to have been latecomers to the GIS realm. Urban and rural planning applications had laid the foundation of GIS for nearly two decades, and judging by the literature, resource management for only half this time. Wildland fire management has been somewhat later yet, and it's only been within the past several years that the urban/rural planning and wildland/wildfire worlds have met in the form of wildland/urban fire applications. I felt a little lonely!

With a head full of ideas, ambition, and lots of good intent, I began working with Dr. Ron Wakimoto to develop a plan and procure funding. The Blackfoot Forest Protec-
tive Association provided "seed money" to get us going. Additional funding from the McIntire-Stennis Cooperative Research Program, administered through the University of Montana, allowed us to purchase the needed computer system and some associated peripherals. Then, in July, 1990, after getting the computer, software, and other necessities set up and ready to go, I began working full time in the Fire Management Bureau of the Montana Department of State Lands. It was a great opportunity, but made completing this project a true exercise in persistence.

Why Missoula County as a study area? And why the Rattlesnake Valley? There are several reasons. I needed an area large enough to provide a broad spectrum of wildland and wildland/urban interface scenarios. I also wanted to represent a diverse cross section of the various types of fire protection policies and issues at the local, state, and federal levels. Missoula County proved to be an excellent choice for all of these reasons. In addition, much of the information used, both digital, tabular, and map-based, is available on a county-wide basis through the Missoula County government.

The Rattlesnake Valley made an ideal local-area study for some of the same reasons, and a few different reasons. It is certainly not the only place in Missoula County that has interface problem areas, and not necessarily the worst. However, it does present good examples of several types of interface described in the literature (and in this thesis), plus a wealth of adjacent non-interface residential neighborhoods to serve as a comparison.

The Rattlesnake Valley is one of the fastest-growing areas in the county, and probably has more local politics, controversy, and neighborhood coalitions per capita than most other places. This is due, among other things, to the rapid growth rate, a controversial annexation of most of the valley into the City of Missoula in 1989, and
conflicts between recreation, open space, wildlife habitat, and residential land use
issues centered around the Rattlesnake Creek corridor, the Rattlesnake Wilderness at
the north end of the valley, and hillsides adjacent to the main valley. Local citizen
involvement is alive and well in the Rattlesnake!

I'd like to mention briefly the issue of data collecting and editing, even though
Chapter 3 gets down to the nitty-gritty, because it was the most time-consuming and
trying part of the study. Jon Skinner began his M.S. thesis work at roughly the same
time I did. He, too, was interested in exploring fire management applications of a
GIS, primarily in lightning-caused fire risk. The land area covered by Missoula
County was adequate for his research needs, so we worked cooperatively on acquisi-
tion and entry of data and map layers. I am grateful to him for his work; much of the
data collected for this study was the direct result of his time and diligence.
1.2 STATEMENT OF THE PROBLEM

"From the roof of my car, I saw the fireline cross Mulholland a hundred meters in front of me. The flames consumed the cars like so many dried logs, and their occupants would either jump out, or -- if there was no time for that -- jerk and squall in the flaming interiors...

It was fast. With flames the wind became a smoke-bound monster, making it almost impossible to see...

A scream erupted from every throat. The Doyles' condo literally exploded in black smoke and dark red flames, and then the fire was down to the next group of units...

People ran wildly down the steps to the far edge of the complex and stared peering over the ridge. Sparks were cascading around us, and its sprinklers were already going...

I'm not accusing the developer: everything worked as advertised. It's just that it didn't matter. The sprinklers weren't enough. Nothing was enough."


Wildfire in the suburbs -- the wildland/urban interface. What began in the 1970s as a slow migration of people from cities into rural, mostly forested areas has now become a major exodus. Uncontrolled growth in interface areas persists, and the problem has escalated to crisis proportions. Consideration of emergency services planning and infrastructure in the interface is often little more than an afterthought.

We have witnessed the tragic results in the national news media each year as hundreds of homes go up in flames in massive, destructive wildfires. In the book "Nature's End" (Streiber and Kunetka, 1986), a vivid description of a destructive interface wildfire in the future illustrates the frustration of present-day fire managers; despite the best of efforts and intentions, these fires seem destined to happen, now and for years to come. The 1991 Tunnel Fire in the Oakland hills became one of the most infamous for its sheer force and large-scale destruction. Unlike Oakland, interface areas in Montana typically develop in outlying rural areas. Growth rapidly outstrips infrastructure, and poorly funded, largely volunteer fire protection organizations are saddled with the immense task of protecting high-value residences scattered across large tracts of fire-prone lands.
Fire service and wildland agencies alike have risen to the challenge, but often even the most concerted efforts result in only incremental changes in the status quo -- even in the wake of tragic, destructive fires. Structural fire agencies have had to become adept at both wildland and structural suppression tactics, and wildland agencies increasingly must cope with people and structures in and near wildland management areas. Additionally, fire suppression forces face greater danger in battling interface blazes due to the mix of homes and heavy fuel concentrations, often in steep terrain with poor access routes.

Missoula County is no exception; wildfires have repeatedly threatened or destroyed residences. The Pattee Canyon fire of 1977 burned 1,600 acres of forest and houses on the outskirts of Missoula (Holloron and Fleming, 1977), and sounded a wake-up call to fire protection entities throughout the region. Fire suppression techniques and inter-agency cooperation have continually improved since that time. Nevertheless, each year brands an escalating potential for a large-scale disaster, and unprecedented residential growth in recent years has multiplied this problem.

In all reality, no fire protection system, no matter how well-organized and funded, can cope with the destructive force exhibited by wildland/urban interface fires. Most of the losses typically occur within just a few hours from the start of a fire -- sometimes on the order of hundreds of houses. Growing experience with tragic fires challenges fire managers to prevent other, possibly worse, disasters in the future. This becomes possible only by thoroughly understanding the complexities of the issue and making informed, committed decisions.

As we enter the "Information age," technology and information are becoming critical components of problem solving; this is especially so in the fire and emergency services. Fire protection organizations are faced with expanding emergency response demands, such as the wildland/urban interface, and shrinking budgets. Local fire services in particular have begun searching for innovative ways to deal with this situation. Increas-
ingly, they are joining forces with wildland agencies and are exploring new technologies that can provide them with new tools, such as GIS, to face their most problematic issues.

1.3 OBJECTIVES

The overall objective of this study is to demonstrate the use of a geographic information system (GIS) as a baseline for wildfire pre-suppression and prevention planning in wildland/urban interface areas of Missoula County. This study was never intended to solve all the interface problems of Missoula County, or of any of the governmental bodies or agencies that lie wholly or partially within its boundaries. Rather, the intent was to investigate and demonstrate some of the analytical capabilities of a GIS that can serve as a powerful tool in assessing as complex and multifaceted an issue as the wildland/urban interface.

Specifically, the four primary objectives are:

1. Model broad-area fire behavior potential and compare the simulated distribution of projected flame length and rate of spread for two hypothetical weather scenarios in Missoula County.

2. Determine and compare the spatial distribution of "defensible space" around human structures located in the Rattlesnake Valley based on vegetation, topography, roof type, and two hypothetical weather conditions.

3. Compare the spatial distribution of lightning-caused wildfires versus human-caused wildfires, and the relationship of fire occurrence to population density, proximity to roads, and land ownership.

4. Assess the spatial distribution of fire jurisdictional areas associated with various fire service organizations and wildland fire protection agencies in terms of their overlap and relationship to large historical fires in Missoula County.

There are some areas for which the analyses may seem somewhat superficial, and even stop before reaching what to some readers appears to be a logical end. In these instances, further analysis and application necessarily would be driven by agency-
specific policies, directives, and fire protection needs. Where this occurs, the narrative about the analyses will indicate so.

1.4 SIGNIFICANCE OF THE STUDY

The primary objective from a fire management perspective is to diminish the potential for loss of life and property, and destruction of natural resources, by increasing the efficiency and cost-effectiveness of various aspects of wildland/urban interface fire protection and planning. This includes the identification of high-priority areas for wildland fuel modification and hazard abatement programs, and contingency planning for initial response and extended attack on interface wildfires.

The development of a comprehensive information base for areas in and near this interface is vital for effective fire prevention and pre-suppression planning. Several efforts have been made in recent years to delineate wildland/urban interface areas in Missoula county and create accompanying wildfire hazard and fire occurrence maps. However, due to constraints imposed on the individuals responsible for these efforts, and the fact that the effort as a whole has been fragmented between several different agencies and working groups, there has not as yet been a single, coordinated effort to produce a comprehensive mapping system and database for analysis and eventual resolution of the problem.

In Missoula County, hazard identification and mitigation work in particular has been limited. Each agency in each area of the county has commonalities with others as well as specific ideas as to their own needs, and each has their own biases and beliefs. To date, much of this information has not been documented and exists only in the heads of those individuals involved (Wakimoto, 1990). Development of a GIS information base, with its extensive analytical capabilities, is becoming increasingly important as a means of standardizing information sources and providing information useful to fire protection officials and resource managers.
GIS-based hazard identification and mitigation analyses can be valuable tools for several reasons. First, it lays the groundwork for a "structure triage" ahead of time. Fire managers know which houses are at greatest risk, based on specific local conditions -- which may be defensible and which may not, under a variety of weather conditions. This information provides a graphic, persuasive tool to convince homeowners why and how they need to reduce the hazard, and convince local officials of where and how greatly greenbelts and other preventative measures would benefit the community.

What is needed to effectively tackle the problem in Missoula County in light of the great diversity of land uses and concentrations of houses in forested areas is a comprehensive inventory of the many spatial factors which come into play in dealing with the urban interface issue -- hazard levels, hazard initiation recommendations, identification and characterization of risk, housing densities, suppression capabilities of the fire protection agency responsible for initial response, and so on. A GIS-based inventory and analyses, such as that derived from this project, would provide all agencies involved in urban interface fire protection with specific information on each area and serve as a foundation for future cooperative efforts between local governments and fire protection organizations.

1.5 THESIS ORGANIZATION

In writing this thesis, it quickly became apparent that few readers would be versed simultaneously in wildland fire protection, structural fire protection, geographic information systems, and the fire protection systems of Missoula County and their history. I felt that having a baseline of information in each of these areas was important; in trying to pull together these very diverse worlds, I have provided background information in each area.
A brief explanation of how this thesis is organized is in order. Chapter 2 provides a
general background discussion of the wildland/urban interface problem, fire history
in the Northern Rockies, and interface issues in Missoula County. It also outlines the
essential features and capabilities of a GIS, particularly in relation to actual and
potential applications in hazard and risk management pertinent to this project: hazard,
risk, defensible space, and jurisdictional issues. Finally, it provides a brief
overview of the characteristics of the two study areas chosen: Missoula County, and
the Rattlesnake Valley.

Chapter 3 begins the research portion of this thesis with a description of the delineation
of the study area boundaries and organization of map and data layers in the GIS.
It provides documentation on the sources of all map layers and data used in the GIS,
and also includes a description of the map and data standards, and a list of the hardware and software used.

Chapter 4 discusses the limitations of the analyses, including possible sources of
error in data collection, compilation, and analysis. It discusses both the uses and the
limitations of a GIS as a spatial analysis tool. Software and hardware issues are also included, although by far the most important factor is that of the data itself.

Chapter 5 describes how the analyses were done and what data parameters were used,
and provides graphical and tabular displays of the results. Chapter 5 also includes
some discussion of the results, particularly where further analyses might be appropriate in the future.

Finally, Chapter 6 summarizes the research and discusses some future implications
for this type of work.

For quick reference, a list of literature cited, and lists of figures and tables, are in-
cluded. I have also included a set of appendices to provide more detailed background information for this study. In addition to a glossary of terminology, other appendices were included to provide more detail for those readers who desire further background information concerning fire protection issues in Missoula County, and more information about the GIS data used in the study.

Five years and many, many, cups of coffee later, this study has come to a conclusion. It is by no means finished, though. The processes of risk analysis, hazard assessment, and planning are ongoing processes. A working GIS necessarily needs to reflect this. I hope that some of the fire managers and planners in Missoula County (and possibly elsewhere) will be able to use information from this thesis in future endeavors, either for agency-specific needs or to support interagency cooperative efforts. If it results in just one change for the better, this study will have been well worth the struggle.

The Fire Side
By Paul D. Modjeski

O.K.... TRY THE NEXT BUCKET.

EARLY EXPERIMENTS IN FIRE SUPPRESSION
Chapter 2.

BACKGROUND: FIRE, POLITICS, AND GIS

"It just goes to show you -- it's always something!!"
-- Roseanna Rosannadanna; Saturday Night Live

2.1 THE WILDLAND/URBAN INTERFACE FIRE PROBLEM

The term "wildland/urban interface," often referred to simply as "interface," was first formally introduced two decades ago (Butler, 1976), and was used to describe the point where man-made fuel meets natural [wildland] fuel. Similarly, Lee (1980) defined the wildland/urban interface as "any point where the fuel feeding a wildfire changes from natural (wildland) fuel to man-made (urban) fuel." In such areas, fire protection and prevention issues of urban areas and wildland areas intermingle to create a complex problem for homeowners and fire protection agencies (Davis, 1989).

The following sections discuss aspects of the wildland/urban interface as a national issue. Please refer to Appendix A for a list of terminology used in this and other chapters.

2.1.1 National Issues, Politics, and Policies

Even before it had a formal name, or associated terminology and jargon, the wildland/urban interface has long been an issue in the U.S. The first well-documented interface fire was the 1871 Peshtigo Fire in Wisconsin. This fire burned hundreds of thousands of acres of forest, destroyed several towns, and resulted in 1,200 deaths. Since then, many other wildland fires have wreaked havoc with human civilization and its "outposts."

Recent examples include:


Not only do wildfires threaten the lives and property of residents, but wildfires starting in or near residential subdivisions can damage valuable watershed, wildlife, timber, and recreational resources. When structures are present, wildland fire managers must radically alter their suppression strategies. Houses take priority, and excessive losses of natural resources often occur as a result.

Conversely, structural fire agencies often have insufficient resources to cope with a large wildfire, and the number of structures threatened in a major conflagration can quickly overwhelm structure protection and suppression forces. In addition, hazardous wildland fuels and limited road access present serious safety problems for firefighters.

The first step in solving the problem is to recognize it. The problem itself has been very well identified — at times to excess. As early as 1975, national efforts were underway to strengthen rural fire protection and reduce annual losses through the pilot Rural Community Fire Protection program (USFS, 1977). As evidenced by the list of recent interface fires above, however, the problem is far from solved. The next steps are to devise solutions, implement programs to mitigate the problem, and evaluate the results. This is where a GIS can be a valuable tool in risk analysis and fire management planning.
2.1.2 Types of Interface

In Standard 299, the National Fire Protection Association (NFPA) describes three types of interfaces, all of which are found in Missoula County (NFPA, 1991b). The first, "wildland/urban interface," or "classic," is where city and suburban areas meet wildland vegetation with a relatively well-defined boundary. These areas present the greatest potential for structure loss in a single fire. Adjacent areas with continuous flammable vegetation can propagate a massive flame front with long-range spotting potential.

The second type, "wildland/urban intermix," or "mixed," consists of homes and other structures intermingled with wildland vegetation in a more dispersed manner. This type of interface presents the greatest problems for fire protection due to the often rapid growth rate, minimal planning, and inadequate infrastructure of these areas.

The third type of interface, "occluded," consists of islands of flammable vegetation enclosed within a developed area. Examples of this include open space preserves and "natural" parks, and wooded river bottoms located within urbanized areas. Although not as great a problem as the other two types of interfaces, the "occluded" interface nevertheless does present a wildfire threat to surrounding communities.

2.1.3 Key Problems

Wildfire Hazard

Wildfire hazard is availability and condition of fuel that can burn and contribute to the spread and intensity of a wildfire -- how readily a fire burns once started, and how difficult it is to control. The relative level of hazard is fundamentally described in terms of fire intensity (Figure 2.1.1a and b) and rate of spread, and is important in highlighting potential fire control problems. Fire intensity and rate of spread are driven by the inter-relationship of the fuels, topography, and weather (NWCG, 1981).

Knowing the type and degree of hazard present indicates what types of suppression resources fire can be used to fight a fire, and whether structures can survive a wildfire
unattended. Topography and weather are beyond the control of fire management personnel, and fuel modification is not always feasible on a large scale. However, it’s possible to at least identify the hazards and potential for ignitions and determine the potential for development of a large-scale disaster.

The fuel environment is a key element of the fire hazard in the interface. There are two distinct components of the fuel environment that form the wildland/urban interface --
flammable vegetation on one side, and flammable building materials on the other. These fuel complexes require a wide variety of fire suppression tactics traditionally used by different agencies. Wildland fire suppression tactics typically employ a mobile approach; the fire is not necessarily constrained to one particular area. Once deployed, fire suppression forces can relocate to areas of greatest activity, and when necessary, can pull back to secondary lines and burn out the intervening fuels. Fire service organization resources, on the other hand, generally are more geographically stationary. If the fire grows, additional resources are put into place accordingly (Foote and Cole, 1993)

The types of fuel complexes are also important in the spread of a wildfire. Fuels represented by structures affect the spread of an interface wildfire primarily by the production of firebrands -- airborne embers. These firebrands can ignite new spot fires ahead of an advancing flame front and escalate the intensity and spread of the fire. However, the wildland fuel component is the primary element in the intensity, rate of spread, and destructiveness of an interface fire. Wildland fuels have received great attention recently in that they are the one single component of the interface complex that can be readily altered, with a concurrent and dramatic reduction in the wildland fire problem.

Defensible Space and Hazard Mitigation

"Once upon a time, a rural fire chief placed green rocks near the entrance to the driveways of forested homes that he believed he could protect in the case of a forest fire. He placed red rocks at the driveway entrances to homes where lack of clearance, narrow or steep driveways, flammable construction, or other features made protection impossible or too hazardous for his firefighters. No protection would be given to these homes. When the homeowners found out what the colored rocks meant, the chief almost lost his job -- but he made his point." (Davis, 1990).

Where the exterior construction of a house is made of flammable material, the buildup of adjacent flammable vegetation and other fuels presents a dangerous situation; the proximity of a structure to flammable vegetation, and the flammability of the structure's roof, is directly related to its vulnerability in a wildfire. Defensible space is an important means of mitigating the wildland vegetation hazard. It's a buffer zone around a structure
within which flammable vegetation has been cleared or reduced. It includes removing all surface fuels and ladder fuels to eliminate horizontal and vertical fuel continuity near the structure, and generally refers to an area at least 30 feet in all directions around a house on level terrain (CSFS, 1991).

The basic premise of defensible space is that it reduces heavy loadings of vegetative fuels far enough from the structure to prevent ignition of the building by radiated heat or direct flame impingement (Figure 2.1.2). It also provides a safe area in which firefighters can work to defend a structure (Moore, 1981). Defensible space can include backyards, parks or green belts, irrigated pastures, or empty lots.

The closer a home is to flammable vegetation, the greater the odds that it will be destroyed in a wildfire, and a greater number of homes with wood roofs are destroyed than homes with fire-resistant roofs. One case study in particular illustrate this point very well (Figure 2.1.3; Moore, 1981).

Davis (1990) provides several examples where vegetation clearance and fire-resistive
roofing made a clear difference in a structure’s survival in a wildfire. He also reviewed data collected following a destructive interface fire in Florida; not only did vegetation clearance reduce the loss of homes in this fire, but the construction was shown to be important as well (Figures 2.1.4, 2.1.5).

Because suppression forces may be limited in numbers, or overwhelmed by the size and
intensity of a fire, defensible space is critical in whether a structure will survive a wildfire or be destroyed. In 1991, these factors came together in the Oakland Hills to create one of the worse wildland/urban interface disasters in history—the infamous Tunnel Fire.

"It is apparent that very few homeowners in the Oakland and Berkeley fire area provided fuel breaks around their homes. In fact, many of the homes in the most devastated areas were shrouded under large Monterey pines, eucalyptus, and other trees. Most of the eucalyptus trees had many dead branches, caused by a hard frost the previous winter, and nearly all flora was extremely dry after five years of drought" (Kluver, 1992).

In the Tunnel Fire, structures ignited at an average rate of 13 every minute (NFPA, 1992). As in nearly every other catastrophic interface fire, the rapid destruction of structures was attributed to a combination of flammable roofs and accumulation of adjacent flammable vegetation and fuels.

The conclusion is clear: defensible space makes a very definitive difference in the survivability of a structure. The more hazard mitigation steps a homeowner takes to reduce the amount of flammable vegetation around a house, the less likely the house will be destroyed in a wildfire. The flammability of the roof and building construction features are important factors as well. However, there are no guarantees. Other factors are important: reducing the risk of ignitions, not building in areas prone to faster-moving fires (steep slopes, canyons), and ensuring an adequate infrastructure for firefighting.

"Structure triage" is a new firefighting tactic used in interface areas (Cowardin, 1992). The basic premise of triage is to "sort by priority," a common practice used by emergency responders in large-scale disasters with multiple victims. The same principle applies to structure triage. In an interface fire, there are often scarce suppression resources relative to the number of structures threatened. These resources must be allocated to the most critical needs to maximize effectiveness and minimize losses.

In order to do the most good with available firefighting resources, firefighters classify, or "triage," houses into three categories: needing little or no attention for now, needing
protection but saveable, and hopeless -- the “write-offs.” Homes are quickly classified into these categories based on characteristics of the structure, surrounding fuels, fire behavior, available resources, and firefighter safety. A key element in a structure’s survival, and in receiving a higher protection priority in the face of a wildfire, is in the existing defensible space (NWCG, 1991).

Hazard mitigation at the interface presents a strong dichotomy. Urban fire hazard mitigation is typically accomplished through mandatory compliance with fire safety codes, codes based on years of fire protection engineering, research and product testing. At the interface, however, hazard mitigation has relied on education efforts and voluntary adoption of fire safety recommendations based on professional judgement and case studies (Foote and Cole, 1993).

There have been a few success stories in achieving adequate hazard mitigation in interface areas, such as the mandatory brush clearance ordinance enacted by the City of Los Angeles (Haworth, 1989). Mandatory vegetation clearance programs are rare, however, and the continued loss of large numbers of homes in interface fires demonstrates the poor effectiveness of voluntary programs. Fire codes comparable to those used in urban fire safety remain an elusive goal. Much of this is due to the resistance of homeowners to changing their environment, and part is also due to the sheer number and diversity of agencies and public entities often involved in interface issues.

Foote and Cole (1993) point out that a handful of destructive urban fires, such as the Great Chicago Fire of 1871, the Coconut Grove fire of 1945, and the MGM Grand Hotel Fire of 1980, led to sweeping changes nationwide in improved awareness, development of fire safety codes and education, and adoption of stricter building codes. The Great Chicago Fire alone resulted in approximately 300 deaths; interestingly, on the same day, a forest fire near Peshtigo, Wisconsin, destroyed several towns and resulted in the deaths of 1,200 people. Yet this fire, dubbed “the most lethal fire in North American History,”
has slipped into relative obscurity within the fire service.

Although much the voracity of the 1991 Tunnel fire's spread was attributed to a combination of highly flammable fuels and combustible roofs, many of the houses rebuilt after the 1991 fire, some of which had also been destroyed in a wildfire in 1970, were once again constructed of flammable exterior materials. A municipal ordinance requiring the use of fire-resistant roof materials was passed in 1923 after the first interface fire in Oakland, but immediately rescinded due to public outcry (NFPA, 1993).

In general, the public and the media seem to have a relatively short attention span after a destructive interface fire. A documentary of the Oakland (CA) fires illustrates this point:

"On the ferry, we sat and saw the city... literally going up in hot, black clouds. wildfire covering the hills with a writhing mass of flame. No sight of excess in nature can be more terrible, even at a distance, than the rolling and wallowing and climbing and pitching of the fire in the wind. We sat hypnotized as the ferry turned ahead."

-- Eyewitness account, 1923 Oakland fire.

"Each home was a gigantic bonfire, with sheets of fire reaching high in to the surrounding trees, torching the pines and spreading the flames. Ashes, burned branches, and downed telephone lines covered the streets... By 4 p.m., 37 homes were destroyed and 18 damaged... As night fell, tiny fingers of flame flickered in the valleys, the last embers of a holocaust we shall not soon forget."

-- Video narrative; 1970 Oakland fire.

"The fire burned with such intensity that it consumed 790 structures within the first hour. Many of those same homes destroyed in the 1970 fire were once again consumed... A canyon that was lined with million dollar houses and dense forest is now a moonscape, with nothing left that could not withstand fire temperatures of 2,000 degrees [Fahrenheit]."


One phenomenon in particular contributes greatly to the difficulty in focusing attention on the interface problem and possible solutions -- the apparent resistance to government regulations displayed by the people living in the interface. Social scientists studying the wildland/urban interface phenomenon have identified this as a "frontier attitude of independence" on the part of the people moving there (NFPA et al., 1987). As such, any government mandates are not generally well-received. However, the public must understand that the fire service cannot mitigate the interface hazard alone. "By the time fire breaches the interface and crosses from wildland to urban fuels, it might be too late"
"Property rights" in the U.S. have recently emerged as a significant issue in more rural interface areas, and generally allow owners to pursue any activities that are considered "reasonable." And because historically there have been no state laws that specifically address wildfire hazards, and relatively few households have been impacted by wildfires, hazard mitigation has not been an issue of great significance until recently (Gardner and Cortner, 1988).

The costs of wildfires are not borne solely by the affected homeowners. Because the suppression effort comes from public entities (local, state, or federal firefighting forces), the costs are borne by the population at large. In the absence of sufficient incentives for hazard mitigation in the interface, homeowners continue to create dangerous situations by building homes in fire-prone areas.

The threats posed to the public, and the incurred fire suppression costs associated with the continued buildup in the interface, ultimately are borne by all. In the absence -- and often defiance -- of voluntary hazard reduction programs, policies relating to hazard mitigation are primarily intended to modify the behavior of those who choose to continue living in hazardous areas (Gardner and Cortner, 1988).

Resolving interface problems will take a joint effort on the part of the public, fire protection organizations, and public officials.

"The fire service can most effectively respond to the interface threat as it has responded to other potentially overwhelming hazards: by shifting the hazard mitigation burden onto the parties who create the hazard. Those who profit from and enjoy the amenities of building and living in the interface must be willing to take responsibility for protecting life and property by funding additional mitigations, regardless of whether they are mandatory or voluntary." (Foote and Cole, 1993).

Capabilities of Local Fire Protection Agencies

Fire protection in interface areas presents a stark contrast between needs, perceptions,
and reality. It is often provided by volunteer fire departments with limited funding that is inadequate to address the complex needs of interface areas. The result is a severe mismatch between the property owners' perceptions and expectations for fire protection and the protection strategies developed by local fire service organizations (Davis, 1987). The very nature of interface areas almost precludes the possibility of adequate fire protection. Structural fire protection, which realistically involves both structural and wildland agencies, too often receives little consideration in planning processes.

During critical fire seasons, suppression resources are often limited and the service demand generated can quickly exceed capabilities. When wildfires occur near homes, the protection priority shifts to saving structures at the expense of natural resources. The pool of resources immediately available is typically inadequate to deal with even minor conflagrations, and in the case of major conflagrations, as was the case in Pattee Canyon in 1977, the extreme intensity and rate of spread of the fire limited the effectiveness of any suppression actions (Fischer, 1977).

Unfortunately, the main focus has been on the initial attack of increasingly frequent small fires. This has obscured the importance of addressing fundamental issue of hazards and situations that threaten lives and property on a broader scale. The increasing numbers of people relocating to these areas, the limited availability of fire protection personnel, and the escalating cost of facilities and equipment, point out the need for emphasis on effective fire prevention programs as a first priority (Bowman, 1978).

The Insurance Industry
The difficulty in obtaining public involvement is exemplified by the apparent indifference of the insurance industry. The level of wildland hazard in an area is not normally directly accounted for in annual premiums for homeowner insurance in Montana. Until a particular home or homes in an area have been replaced more than once, insurance companies do not increase rates, and the rate increases are based on the individual loss
rather than any hazardous conditions of the area.

Most insurance companies use the Insurance Services Office (ISO) ratings of areas to obtain homeowner insurance rates. ISO uses a “Fire Suppression Rating Schedule” (FSRS) to delineate 10 different classes of municipal fire protection. The FSRS takes 14 major factors into account in developing these rates, including distance from fire stations, water availability, number of personnel in the responding fire department, and the actual historical losses within an area (Foster, 1988). To date, the ISO ratings still do not account for wildland hazards - other than indirectly through historic loss of structures.

In the case of the Pattee Canyon fire near Missoula in 1977, each house was covered by a different insurance company; all houses in the path of the fire were destroyed, but each company had to replace only one house. Insurance companies often make no distinction between houses lost to wildfire vs. burned from within, and the occasional replacement of one house from loss by fire is considered to be within acceptable limits (Dove, 1990).

2.2 STUDY AREA BACKGROUND

Two research areas were chosen for this study -- the entire area of Missoula County, and the Rattlesnake Valley which runs north of Missoula. The purpose of having two study areas, the smaller one entirely contained within the larger, was several-fold. The social and political issues on a county-wide scale are very diverse, providing a backdrop against which to assess a similar diversity of interface areas. The county as a whole also provided the quantity of fire occurrence data necessary for a meaningful study of risk. The county, and particularly the Missoula Valley (Figure 2.2.1), also has many intermingled fire protection jurisdictional areas, and quite a lot of interjurisdictional planning and fire protection issues that result.

A smaller area within a single drainage, the Rattlesnake Valley, allows for an analysis of more locally based facets of the interface issue such as defensible space and [home] site-
specific hazard mitigation. These would be very difficult and time-consuming to do at the county level, and is beyond the scope of this study. The Rattlesnake has been an interesting political battleground for heated conflicts between residents and the City of Missoula over many things, including fire-related issues (Appendix E). It was also host to the first attempt at bridging the gap between the Missoula Fire Dept. and the Missoula Rural Fire District, setting the stage for more cooperative ventures in years to follow. The following sections profile the interface problem, and related issues, in the northern Rockies (2.2.1), Missoula County (2.2.2) and the Rattlesnake Valley (2.2.3).

2.2.1 Fire History in the Northern Rockies -- the Development of a Problem
Fire is an integral part of the natural processes in the Northern Rocky Mountains. In fact, the forests here were literally “born of fire.” In western Montana, fire has historically burned in any given area every 6-41 years (Arno, 1980), and a return interval of 3-30 years is common under older stands of ponderosa pine (Gruell et al., 1982). Once organized fire suppression efforts began in 1920, the incidence of wildfire decreased markedly, accompanied by an increase in the return interval of fires. The lack of periodic “cleansing” fires has led to an accumulation of woody fuels on the ground and heavy growth of a dense understory that promotes spread of fire into the crowns of trees.
The intensity and size of wildfires has increased dramatically; relatively mild surface fires have been replaced by less frequent, more destructive crown fires (Arno, 1976).

Earlier in this century, wildfire often threatened natural resources in Montana, but only occasionally posed a problem for residences due to the concentration of people near major population centers. However, the trend in recent years has been towards migration of people out of the more heavily populated areas and into fire-prone wildlands.

People living in "intermix" areas typically have a perception of forestry that "clashes with ecological reality" and encourages fuel buildup. They tend to underestimate the danger presented by the highly flammable vegetation surrounding them, the very vegetation that they consider so beautiful and desirable. There is typically strong resistance on the part of residents to any restrictions or ordinances, although they expect the fire organizations to resolve the issue (NFPA et al., 1987).

2.2.2 The Interface Fire Problem in Missoula County

"A lot of the growth there [the interface] is people who are fed up with the city [of Missoula]. They are tired of high taxes and not being able to change anything, and just want to live off in the trees and be left alone. I'm not saying it's right or wrong, it's just what it is." (Geiser, 1994).

The City and County of Missoula are both growing in population, and this in turn has resulted in more growth in the interface. There are a large number of diverse interface areas throughout the county, from smaller communities protected by rural fire districts to the more urbanized areas of the Missoula Valley. New construction continues in areas with heavy accumulations of wildland fuels. The "intermix" type of interface is by far the most common scenario in Missoula County. Although most growth is occurring outside areas of commercial vegetation types, many of these developed areas are adjacent to commercial forests.

Wildfires originating in these areas can cause serious damage to this important part of the local economic base, and fires originating in forested areas threaten the lives and prop-
In fact, wildfires have repeatedly threatened or destroyed homes in Missoula County. The first well-documented interface fire occurred in 1919. Reaching a size of 45,000 acres, this fire burned across the north end of the Rattlesnake Valley, and destroyed homes and outbuildings (Poe and Poe, 1992). History repeated itself in the same place with the LP Mill Fire of 1991 (Fig. 2.2.2). Other recent wildfires have threatened or

Figure 2.2.2. Then and now... In August, 1919, a 45,000 acre wildfire swept across the upper Rattlesnake Valley, ignited by careless debris burning in the adjacent Grant Creek drainage, and pushed by 50 mph winds (Missoulian, 1919). Then, in 1991, a dry cold front in October brought winds gusting to over 50 mph to the same area. The "LP Mill Fire" started as a structure fire and spread onto a nearby field and toward the Rattlesnake. Hundreds of people were evacuated (Jahrig, 1991).
destroyed homes, illustrating the difficulty fire protection agencies face in effectively solving the problem. The scars of two of these fires (Pattee Canyon and Hellgate Canyon) are still plainly visible from most points in Missoula and serve as a constant reminder of the area’s vulnerability to wildfires. One does not have to look far back in time for other such reminders:

- In 1977, the Pattee Canyon Fire destroyed 1,200 acres of forest and 6 houses within a few hours (Holloron and Fleming, 1977).
- The Mill Creek fire of 1979 destroyed 1600 acres of forest and came within 1/4 mile of residences (Missoulian, 1985).
- In 1979, a 250-acre fire 2 miles north of the Grant Creek Development in Missoula forced the evacuation of the area (Missoulian, 1985).
- Madison Gulch fire in 1988 threatened homes and forced the evacuation of several residential areas (Missoulian, 1988).
- The Lolo Creek fire in 1988 burned over 2000 acres of forest and threatened numerous homes.
- Several other fires in Grant Creek in 1985, 1987, and 1988 again forced evacuation of residents (Missoulian, 1987a, b, and c).

The Pattee Canyon fire of 1977 is the most well-remembered of these (Figure 2.2.3). In
this fire, which burned just outside the Missoula city limits, the dense forest cover and steep slopes provided ideal conditions for an intense crown fire (Figure 2.2.4). Within minutes of the start of the fire, strong winds fanned the flames into the crowns of the trees, and any houses in the path of the fire were incinerated in a short time (Fischer, 1977; Figure 2.2.5). A few homes escaped destruction, likely due to a combination of
fire-resistant construction and a little luck (Figure 2.2.6).

Then there was the fire season of 1994, a record-setting year in many regards. Western Montana had far more wildfires in 1994 than in even the infamous fire season of 1988. In 1994, neighborhoods in the Grant Creek drainage were threatened on two separate occasions by fast-moving wildfires. One, a 75 acre fire in late July, burned so close to houses that burning debris rolled into several people’s yards. Yet even after two close calls in the same year, it appeared that many residents were content to go about “business as usual.” Having dodged the bullet once again, they seemed secure in the belief that an overwhelming, coordinated ground and air response would always be there to protect them. In fact, so confident were the residents in this regard that many lined up along the main road in the valley with lawn chairs, ice chests, and cameras to take in “the show” during fire suppression operations. Afterward, heavy accumulations of pine needles remained on many of the untreated cedar shake roofs for the duration of the fire season. “Defensible space” was another good idea that was quickly forgotten.
2.2.3 The Missoula County Study Area -- Geography, People, and Politics

"...It's [Missoula] more like a group of clans ... contentious clans... One group organizes to support something, and by gosh, within 24 hours there's a group organized against it."

-- Ann Mary Dussault, County Commissioner (Cunningham, 1991)

Diversity of Land Use

Missoula County encompasses a total area of 2,625 square miles and ranges in elevation from 2,900 feet to over 9,000 feet. General terrain features are shown in Figure 2.2.7 (see Figure 5.1.1 for actual elevations). Its diverse land base is managed, owned and used by a variety of government agencies, private corporations, and individuals. Within Missoula County lie part or all of four federally designated wilderness areas, large tracts of commercial timber-producing areas, scattered residential developments, heavily used recreational areas, the urban core of Missoula, and surrounding subdivisions and industrial areas. Land ownership is a mixture of private, private-industrial (timber), State of Montana, etc.

Figure 2.2.7. Perspective View of Missoula County, looking to the north-northwest. Major highways are indicated. Vertical exaggeration is 3.0x.
Land Ownership

Figure 2.2.8 shows the predominant land ownership classes in Missoula County. Prior to 1992, there were two private industrial land ownerships: Champion International, and Plum Creek. In 1992, Plum Creek purchased all Champion lands, making Plum Creek the largest private landowner in the county, and the single commercial timberland owner.

Figure 5.3.7. Predominant land ownership in Missoula County as of 1992.
Diversity of People -- Local Jurisdictions and Citizen Involvement

Missoula County is characterized by a very decentralized type of governmental control; constituents in Missoula County generally want decentralized authority. It is a complex mixture of local jurisdictions, each with its own separate elected board and taxing jurisdiction, plus a municipal fire service within the Missoula city limits. The following quote by a former Missoula County Commissioner, also a former State Legislator, reinforces this point:

"...as they (State legislators) deal with local governments or local jurisdictions...[they] tend to impose a decentralized authority at the local level. And that decentralized authority can make it very difficult for those of us who work in these local jurisdictions when we view a problem, to come up with simple solutions. ...I would love to be able to define an issue, to bring together a group of informed, intelligent local citizens, and come to a consensus on the solutions, and then simply impose them. Well, in a jurisdiction like Missoula County, that's simply not possible to do. ...We respond far better when there's been a problem and we can find a simple solution rather than working our way through the complexities and trying to think how to prevent something in the future" (Dussault, 1988).

Citizens of Missoula County have a history of and reputation for strong involvement in local political matters. Missoula itself is home to numerous neighborhood watchdog groups, where there is "...much ado about practically everything... Missoulians march, protest, sit in, organize, petition, write letters, form advocacy groups, join coalitions..." (Cunningham, 1991). In the same article, County Commissioner Ann Mary Dussault, in speaking of Missoula, stated, "One group organizes to support something, and by gosh, within 24 hours there's a group organized against it."

The bottom line, however, is that County Commissioners are simply not going to devise rules and regulations to deal with the interface problem unless there is substantial support from the public. Solutions are generally reactive rather than proactive. Too often, it takes a disaster to generate public support (Tokle, 1987).

Planning and Subdivision Review: "What -- Me Plan?"

Public officials at the county and local levels continually contend with criticism regarding planning. People living in and near the urbanized area of Missoula tend to want more planning, while those living in more rural parts of the county want less. Striking a
balance is difficult. However, the continuing residential development in interface areas, without adequate infrastructure for fire protection and other service needs, points to a critical need for effective planning.

Generally, residents of the Missoula area are inclined to want focused, effective planning; the Missoula City Council and regional planning officials have been the target of strong criticisms for creating plans that are never implemented (McGrath, 1992; Figure 2.2.9). The defeat of a 12-year incumbent County Commissioner in 1994 was attributed by many largely to open space and growth issues. Some key criticisms aired by her opponent centered around what he believed was not a tough enough stance against developers in preserving open space and building infrastructure.
Lack of a solid subdivision review process has been part of the problem with interface development in Missoula County. The Subdivision and Platting Act and the Sanitation and Subdivision Act, passed in 1973 by the Montana Legislature, were intended to place subdivisions under public scrutiny and subject them to minimum standards through a comprehensive review process (Burden, 1980). This was to prevent haphazard development. However, the law also included a number of exemptions, intended to allow for some flexibility for homeowners who were not themselves developers. These exemptions have been used chronically, by developers who wish to bypass the review process.

The existing County Subdivision Regulations did not adequately address the issue of fire protection for proposed communities, particularly in regard to water supply for the areas in question. No mention was made of existing wildfire hazards, past fire frequency, or the potential for extreme wildfire behavior. For properly platted areas, fire protection for subdivisions was given only a superficial review (Dannenberg, 1983).

The 1993 Montana legislature made an important change in state subdivision review laws. Up to that time, a subdivision comprised of parcels 20 acres or larger was exempt from a review process. With the 1993 changes, only parcels greater than 160 acres were exempt from review (MCA, 1993a). Thus, many interface subdivisions that would have previously been exempt from any review were now subject to at least minimal scrutiny.

As of the writing of this thesis, an important change in the subdivision review process is occurring. Missoula County is in the midst of a three-phase process to overhaul the entire subdivision review process. This process has entailed many meetings between county planners, developers, and wildland and structural agency personnel. Though not as strict as some fire personnel would like, the proposed standards for residential development in interface areas are a vast improvement over what had previously been sorely lacking or nonexistent. These standards were presented in a public hearing on November 23, 1994, and received little opposition. In fact, the response was overwhelmingly
positive from the County Commissioners, fire agency representatives, and developers.

**Residential Growth and Examples of Missoula County Interface Areas**

A variety of interface areas can be found within Missoula County. The following discussion and photos profile several examples of interface areas in Missoula County. For photopoint locations, refer to Figure 2.2.10.

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**Figure 2.2.10.** Schematic map of Missoula County showing photo point locations for Figures 2.2.11 - 2.2.22. Red numbers correspond to numbers in the lower right corner of each figure and the third number of each figure number (i.e., 2.2.11). Where photos are oblique aerial photos, an arrow in Figure 2.2.10 denotes the direction from which the photo was taken. Primary dirt and paved roads, and major highways, are shown for reference.
Most growth of the "wooded subdivisions" has occurred within rural fire districts, which are largely volunteer organizations. Two examples are the Double Arrow subdivision near Seeley Lake, and the Frenchtown Face Area northwest of Missoula. The Frenchtown Face is a rapidly growing area due to its "commutable" proximity to Missoula (approx. 20 miles), and consists primarily of year-round residences (Figures 2.2.11, 2.1.12).

**Figure 2.2.11.** The Houle Creek area north of Frenchtown ("Frenchtown Face" area).

**Figure 2.2.12.** Typical fuels in the Frenchtown Face area.
The Seeley Lake area differs somewhat for several reasons. It's relatively remote from Missoula. It's also a region that's distinct from the Missoula Valley, geographically and politically. And in contrast to the Frenchtown Face area, Seeley Lake has many seasonal residences and cabins in addition to year-round residences (Figures 2.2.13, 2.2.14). The Double Arrow subdivision, located immediately southeast of Seeley Lake, is not growing.

Figure 2.2.13. The Seeley Lake area, viewed from the Double Arrow Lookout tower (looking east). The Bob Marshall Wilderness is seen in the background.

Figure 2.2.14. Aerial photo of the Seeley Lake community.
as rapidly as areas in and near the Missoula Valley, though new construction continues annually. Double Arrow contains a mix of year-round and seasonal/recreational residences, and presents serious fire management problems. Of particular concern are the access problems and continuous, heavy fuels (Figures 2.2.15, 2.2.16).

Figure 2.2.15. The Double Arrow subdivision, located immediately southeast of Seeley Lake.

Figure 2.2.16. Double threat in Double Arrow -- heavy, continuous fuel loadings and poorly maintained powerline corridors are a major concern for fire management personnel in the Seeley Lake area.
Much residential development is also occurring outside of existing organized fire protection jurisdictions. Expansion of existing districts or formation of new districts has not always kept pace with new development, partially due to the inaccessibility of homes to structural fire apparatus. Thus, many scattered homes are currently located outside of any existing fire protection jurisdiction, or receive only wildland fire protection from a wildland agency. An example of this is the upper portion of the Petty Creek drainage, a remote part of Missoula County (Figures 2.2.17, 2.2.18).
Another part of Missoula County, the Ninemile Valley, has historically been considered to be somewhat remote as well. However, escalating housing and property costs in Missoula have driven new development into the Ninemile area. The lower reaches of the Ninemile Valley are within 20 miles of Missoula, and considered "commutable." The concern here is similar to other areas -- limited access, narrow dirt roads, limited local fire suppression resources, and heavy fuels (Figures 2.2.19, 2.2.20).

Most interface growth in Missoula County is outside the urban core of Missoula, often in relatively remote areas. However, the Missoula Fire Department, a municipal fire de-
partment, faces an increasing role in dealing with the interface problem as a result of aggressive annexation efforts by the City. City limits are being driven further into narrow, heavily forested valleys and slopes extending from the Missoula Valley. An area of great concern, Grant Creek, is experiencing extensive new development (Figure 2.2.21). Grant Creek has received heavy development pressure due to its relatively close proximity to Missoula. Concerns in this area include limited access to the drainage via a single road from the south end, heavy fuels, long response times from fire service organizations, and a homeowners’ association that requires the use of wood shake roofing materials (Figure 2.2.22).

Figure 2.2.21. Grant Creek, northwest of Missoula. View is to the north/northeast.

Figure 2.2.22. Part of the Colorado Gulch subdivision in Grant Creek. Despite the high fire hazard in the area, this subdivision has a homeowners’ association requiring the use of wood roofing materials.
Fire Protection

The diversity of land uses within the county has resulted in highly divergent fire protection responsibilities and fire management strategies within relatively small areas and presents serious concerns to land management personnel in terms of fire protection strategies. Wildland fire protection is provided primarily by wildland agencies -- the U.S. Forest Service (USFS), Bureau of Indian Affairs (BIA), and the Montana Department of State Lands (DSL).

Structural fire protection, and initial response to wildfires in the urban fringe of municipalities and in rural areas, is provided by seven rural fire districts, a municipal fire department, and two volunteer fire companies. These are listed in Appendix B. Rural fire districts and municipal fire departments are responsible for all fires, structural and wildland, within their respective jurisdictions. Volunteer fire companies have no jurisdictional areas, but do provide some fire protection to their communities (MCA, 1993b).

Local fire service organizations have a limited capacity to deal with large wildfires. Wildfire protection, particularly extended attack, is provided through cooperative agreements with the (USFS), the Montana DSL, and the BIA, but demands on these wildland agencies during severe fire seasons can limit the availability of suppression resources. In addition, some areas of the County have no legally organized fire protection of any kind.

Fire Politics and “Turf Battles”

Missoula County is rife with “fire politics” -- some more productive than others. The county itself splits geographically, and often politically, into two major valleys: the Missoula Valley and the Seeley-Swan Valley. Within the Missoula Valley itself, the interjurisdictional relations and politics have been the most intense.

Historically, most of the friction between local fire agencies has centered around “turf battles.” Disputes between local fire service organizations in general are not uncommon.
More often than not, they center around the gain or loss of tax base, and a strong desire to retain or increase local control. The most well-known of these in Missoula County has been that of the relations between the Missoula Rural Fire District (MRFD) and the Missoula Fire Department (MFD). A brief history of this is provided in Appendix C.

The solution will not come easily. These political turf battles in the Missoula area have significantly hampered cooperative efforts between fire service organizations. And the complexity of local jurisdictions and the nature of subdivision regulations in Missoula County present a formidable deterrent to a comprehensive planning process.

However, recent years have seen a dramatic increase in the cooperative nature of relationships between local fire organizations. The MRFD and MFD have entered into discussions concerning better coordination of emergency services between the two departments. Local jurisdictions in many areas now have mutual response agreements to ensure a rapid response to fires. And in the age of “reinventing government,” and in the face of continued budget reductions, wildland agencies continue to pursue new and innovative means to work together with local fire organizations to provide a more efficient, cost-effective service. An added benefit to this wildland/structural relationship is that of more coordinated public education and awareness programs.

A Cooperative Approach

Recognizing the need for action in dealing with fire protection issues in the interface of Missoula County, particularly in light of the Pattee Canyon Fire, representatives from 16 wildland and structural fire protection agencies met in 1981 to discuss opportunities for improved cooperation. As a result of this meeting, the Missoula County Fire Protection Association (MCFPA) was formed. It initially included over 300 local fire people, and fire protection was deemed to be the “common element and the responsibility of all members.” MCFPA was designed to deal with issues in prevention, presuppression planning, fuels management, detection, reporting, and training (Bailey et al., 1984).
Fire management personnel of the USFS and DSL, in cooperation with local fire service organizations in Missoula County, have made considerable efforts in recent years to develop wildland/urban interface guidelines for their respective protection areas. However, due to constraints imposed on the individuals responsible for these efforts, and the fragmentation of efforts between several different agencies and working groups, there has not as yet been a coordinated effort to produce a single, comprehensive plan based on analysis of the major biophysical, spatial, and temporal factors involved in fire protection in the wildland/urban interface of Missoula County (Roose, 1990; Bush, 1990). Such a plan is important to minimize duplication of efforts, standardize information sources, and provide information useful to fire protection officials on all levels.

Due to the extensive intermingling of homes and forests, cooperation is vital in order to provide effective fire protection for both structures and wildland areas.

"... As build-up in Missoula's outlying areas continues to increase, so will the need for coordinated efforts between all types of fire agencies. Fire occurrence in rural areas has necessitated the involvement of both structural and wildland fire agencies. To effectively accomplish their tasks, these agencies have had to become familiar with each other's responsibilities, planned actions, and organization" (Peters, 1983).

The Missoula Area Interagency Fire Management Operating Plan, first drafted in 1981 and revised annually since, was the first organized attempt in this direction. It initially involved only three of the organizations in Missoula County (the USFS, DSL, and Missoula Rural Fire District), but currently includes all local, state, and federal fire protection organizations and agencies (see Appendix B for a current list of agencies). Thus, it is now beginning to deal with fire suppression problems in much of the Missoula Valley and vicinity (Appendix D).

2.2.4 The Rattlesnake Valley
The Rattlesnake Valley lies north of the downtown district of Missoula (Figure 2.2.23). About 1,870 residences lie within this drainage, and residential development stretches from high-density suburbs adjacent to the urban core of the downtown district to scattered
residences bordering the federally designated Rattlesnake Wilderness (see Figure 2.2.24 for reference map).

The Rattlesnake Valley is considered one of the more "desirable" residential areas of Missoula, and has faced rapid growth in recent years. As the valley floor of the Rattlesnake becomes more congested, growth continues to spread into the wooded slopes
Figure 2.2.24. The Rattlesnake Valley -- schematic map and aerial photos. Photo point locations and direction of photo (oblique photos) are shown in red. Numbers correspond to the third digit in the Figure number (e.g., 2.2.25).
surrounding the northern half of the valley (Figures 2.2.25, 2.2.26).

Natural vegetation in the Rattlesnake Valley includes grasslands, riparian zones adjacent to Rattlesnake Creek, and heavily forested slopes in the northern part of the valley. Within the valley floor, some natural vegetation remains, but most has been covered with residential subdivisions and re-landscaped. Much of the Rattlesnake Creek corridor, which extends the entire length of the valley, is designated as park land and natural areas.
Nearly the entire corridor is in its “natural” state -- and fire exclusion has resulted in an extreme fire hazard (Figure 2.2.27).

On the forested slopes in the northern part of the valley, a dry ponderosa pine/short grass vegetation type is common at the lower elevations where many houses exist (Figure 2.2.28). At higher elevations, and on northern aspects, a mixed conifer type dominates the landscape.

Figure 2.2.27. The Rattlesnake Creek corridor in the lower Rattlesnake Valley, looking to the west from above Mt. Jumbo. Prior to greenup, and after fall dormancy sets in, this corridor is highly flammable.

Figure 2.2.28. Madera Drive in the upper Rattlesnake Valley, looking to the west-northwest. This area is typical of the ponderosa pine/grass vegetation type found on lower slopes. Note the mixed conifer vegetation type on the north slope (right edge of photo).
Wildland fire protection is provided by the DSL and the USFS, primarily in the northern portions of the valley. There is some overlap between DSL/USFS and the MRFD/MFD jurisdictions. There are also some areas on the east and west extents of the valley that have no organized fire protection. Cooperation between the DSL and the USFS, and between them and each of the structural agencies, has been positive and growing.

**Fire History in the Rattlesnake**

Since the turn of the century, the Rattlesnake Valley has had numerous large fires (Figure 2.2.29). These include a major interface fire in 1919 of which many people aren’t even aware, and other “near-misses.” In this regard, it exemplifies a perspective of interface residents referred to as “cognitive dissonance” -- people know there’s a fire problem, are even periodically reminded of the threat posed by wildfire, but with a lack of fire activity in the recent past, they generally ignore it altogether (Wakimoto, 1991).

![Figure 2.2.29. Fire history in the Rattlesnake Valley, 1919 - 1992; GIS-generated perspective view. Vertical exaggeration is 3.0x.](image-url)
Politics and Public Pressure

MRFD provided fire protection to most of the Rattlesnake Valley from 1968-1989. At the end of 1989, the City of Missoula annexed most of the more populated areas of the valley in a controversial forced annexation. The end result for local fire protection was a mixture of City and MRFD jurisdictions, with a lack of any type of cooperative fire protection agreement (Appendix E).

After lengthy discussions and intense public pressure, the City entered into a mutual response agreement with MRFD. Even this agreement did not fully address the utilization of closest forces, however, since it excluded from MRFD response any areas that had already been in the city -- even if the MRFD fire station was closer.

In the several years following the annexations, numerous lawsuits against the City followed, and discussions between the City and Rattlesnake neighborhood organizations became quite strained. At one point, there was even an organized effort from Rattlesnake residents to disincorporate the City altogether. This campaign proved to be very interesting, but was unsuccessful.

Fire protection has been at the heart of much of the controversy in the Rattlesnake. Following the 1989 annexation, residents' resentment ran high. Emotions, rather than logic, often drove political processes and created a divisive, volatile, atmosphere between Rattlesnake residents and the City government. The history between MRFD and MFD did not help this. Thirty years of feuding between the two departments had hampered vitally needed cooperation efforts, and the greatly diminished tax base of MRFD eventually led to the closing of the fire station located in the heart of the Rattlesnake -- a MRFD station that was squarely within the new Missoula City limits.

Ultimately, the mutual response agreement in the Rattlesnake Valley became the model for other cooperative agreements between the City and MRFD. Though still not operat-
ing under a truly integrated response system, the two departments have greatly improved mutual response in "boundary" areas. Also, a change in several members of the City Council is changing the city's mood to one more of cooperation rather than turf wars.

2.3 GEOGRAPHIC INFORMATION SYSTEMS (GIS)

"Seven and a half million years our race has waited for this Great and Hopefully Enlightening Day!" cried the cheerleader. "The Day of the Answer!"...

"All right," said the computer, and settled into silence again. The two men fidgeted. The tension was unbearable.

"The Answer to the Great Question..."
"Yes...!"
"Of Life, the Universe and Everything..." said Deep Thought.
"Yes...!"
"Is..." said Deep Thought, and paused.
"Yes...!!...?"
"Forty-two," said Deep Thought, with infinite majesty and calm.

-- Excerpt from "The Hitchhiker's Guide to the Galaxy" (Adams, 1979)

2.3.1 The "Essentials" of a GIS

Computers may not always give us the answers we want, and some fire managers still resist the intrusion of computers into the realm of fire protection. Some are quick to dismiss GIS as a toy that is no match for aggressive suppression; others have recognized its value in planning and operations. The technology of GIS is gaining considerable attention, but its capabilities and applications are often not well understood by the very people it could benefit the most.

What exactly is GIS? It's a computer-based system for storing, retrieving, transforming, analyzing, and visualizing spatial data -- information, about map features and their characteristics, that varies over space and time (Coughlan and Olliff, 1988). The two principal components of a GIS are the separate map layers (Figure 2.3.1), and the databases that are linked one-on-one to each map layer.
Each layer typically contains a single theme, such as roads, land ownership, vegetation, population density, or fire protection jurisdictions. The associated database contains specific information about the map features on that layer. Through an overlay process, two or more polygon layers (described below) are merged into a single new layer that contains information from each of the parent layers (Figure 2.3.2).

GIS layers fall into two major formats -- vector and raster. Each has its own unique characteristics and uses for certain applications, and different GIS software programs offer different mixes of vector and raster capabilities.
Fire Perimeters (Class "C" and Larger)

Database Information:
- Date/Time
- Cost per acre
- Fuel Type
- Specific Cause
- Fire Number, Name
- Responsible Agencies

Fire Protection/Jurisdictional Boundaries

Database Information:
- Type of Protection
- Agency Name
- Values-at-Risk
- Fuel Types (from other overlay)
- Assessment Fees/Tax Base

Fire Perimeter/Jurisdictional Boundary "Hybrid" Polygons

New Database Information (for each new polygon):
- Date/Time
- Cost per acre
- Fuel Type
- Specific Cause
- Fire Number, Name
- Responsible Agency (ies)
- Type of Protection
- Agency Name
- Values-at-Risk
- Fuel Types (from other overlay)
- Assessment Fees/Tax Base (from other overlay)

Figure 2.3.2. Schematic drawing of the polygon overlay process. In this example, a large fire perimeter is overlaid with fire protection jurisdictional boundaries.

Vector Layers

Vector layers display vector data — coordinate-based data used to represent points, lines, or polygon boundaries (Kessler, 1992). Vector elements in a map layer are represented by x and y coordinates; when representing elevation or other information, they can also include z coordinates. Vector elements are used to represent two- or three-dimensional information such as roads, hydrography, and point locations, and are also used to delineate polygons (see Polygon Raster Layers below).

By themselves, vectors elements contain little or no real information. They are primarily
useful for displaying boundaries or locations. By linking vector elements with a spatial database, they become map features. Map features then can be linked to a variety of spatial and non-spatial information, and can be used in certain types of spatial analysis such as network allocations. An example of the latter is the determination of the shortest response time from fire stations, given specific attributes assigned to each line segment in a street network.

**Raster Layers**

Raster layers are grid-based layers that organize and display maps or images in columns and rows of “cells” (pixels). There are two distinctly different types of raster layers -- polygon and surface layers.

*Surface raster layers* display a continuum of data that has no readily definable boundaries. Each cell in a surface layer grid theoretically can have any numerical value; a surface layer is only capable of storing and displaying simple x, y, and z data. Examples include elevation maps and proximity-to-feature (distance) maps. Surface layers can be used in mathematical modeling, and are ideally suited for terrain analysis.

*Polygon raster layers* are the converse of this. The grid layer is delineated into spatially discrete regions or *polygons*. A polygon raster layer has an associated database, and each individual polygon has a unique database record associated with it. Multiple polygon layers can be overlaid into a composite layer that includes information from each parent layer (see Figure 2.3.2). Polygon layers are useful for analyses involving information that’s in discrete groupings such as jurisdictional areas, soil and vegetation classes, and has multiple types of information associated with a particular type of map feature or area.

**Database Levels and Types**

A database is a tabular organization of information on a particular subject or group of subjects, and is “governed by a particular scheme of organization. A GIS database
describes distinct map features or areas, and includes information about the spatial location, size, area, and shape of map features (Kessler, 1992).

Most GIS software includes an internal database management system, and also has the capability to port internal GIS databases to an external database manager. There are three types of GIS databases: point, vector, and polygon. These contain information about point, line, and polygon features, respectively. All are spatially explicit, and permit the inclusion of quantitative and qualitative information.

2.3.2 Operational Aspects of a GIS
A GIS allows its users to analyze and view numerous facets of a complex issue at a time, in ways that would be difficult or impossible by conventional methods. It's an ideal tool for comprehensive fire pre-planning in the interface, itself a complex spatial problem. GIS is a powerful tool that is only beginning to show its potential for using information to clarify and resolve complex issues.

Geographic information systems have been applied to a wide array of uses from urban planning in high-density population centers to natural resource inventory and wildlife studies in remote areas. Their utility includes land suitability determination, land use and natural resource inventory, and fire and other natural disaster modeling. In conjunction with a GPS (Global Positioning System), a GIS can be used in the field for such purposes as mapping the changing perimeter of a wildfire and assisting in deployment and tracking of suppression resources.

GIS in Risk Analysis, Hazard Mapping, and Disaster Preparedness
The continued increase in the sophistication of GIS software has allowed a great range of applications in hazard and risk analysis. For example, in Glacier National Park, a GIS has proved effective in using spatial and non-spatial data for graphic analyses of avalanche areas by linking a GIS with a statistical analysis program. Avalanches, like wild-
fires, are a function of slope, aspect, and topographic features. The spatial influence of
topography, lithology, and the structure and location of known avalanche zones were
studied and used to analyze other mountainous areas for the presence of avalanche danger
zones, potentially saving lives and property (Walsh and Butler, 1989).

In the Dallas/Forth Worth (TX) metropolitan areas, a regional agency used a GIS in
conjunction with LANDSAT imagery to model the effects of flood damage. A digital
land use file provides information on current and planned land use, housing construction
and major commercial areas, planned construction areas, and major employer locations.
Thus, the various physical and economic impacts of a major flood can be modeled and
included in future land use planning endeavors (Kruse, 1989). Large wildfires are simi­
lar to floods in that they affect large, definable areas, and would lend themselves well to
the same type of modeling.

**GIS and Land Use Suitability**

The ability of a GIS to analyze and manage a profusion of spatial information makes it a
logical candidate for use in determining land use suitability and addressing conflicts that
arise over the most appropriate use of a given area. This is an important attribute of the
interface dilemma that makes it such a difficult issue to resolve -- the often stark conflict
between people’s perceptions and expectations. As has already been pointed out previ­
ously in this thesis, people living in the interface, particularly “intermix” areas, typically
have a perception of forestry that conflicts with basic ecological principles.

Lyle and Stutz (1983) explored the use of a GIS for land suitability mapping. They
incorporated three primary types of information -- land variables (topography, hydrology,
geology), developmental actions (physical alterations and utilization), and environmental
effects -- to model the potential effects of a particular action. The analyses they com­
pleted for a pilot project area showed great promise in the use of a GIS as a tool to help
determine the best overall uses for land, given competing and sometimes conflicting
proposed uses.

More recently, Berry (1993) wrote about the use of GIS to resolve land use conflicts in a similar manner. He included an important component in the process that was not included in Lyle and Stutz' discussion -- the human element in the decision-making process, and the resulting difficulties in using a GIS for land use suitability analysis despite its extensive spatial analysis capabilities.

In his paper, entitled, “Is Conflict Resolution an Oxymoron?,” he highlights both the capabilities and limitations of a GIS in addressing conflicting and incompatible land uses -- particularly the issue of development versus land preservation. This is a cornerstone of the interface problem; residential development in wildfire-prone land is a setup for conflict, and an invitation for disaster.

Berry used map layers depicting specific types of land uses, including development, recreation, and research or conservation, assigning “greater or lesser-favored” land use values to each. He then used the GIS to determine areas of conflict and the relative level of conflict of each. From this, the competing uses entered into a “conflicts and trade-offs” process. His final conclusion was as follows:

“After a great deal of ‘smoke and dust raising’ about computer processing, the final assignment of land uses involved a large amount of subjective judgement. This point, however, highlights the capabilities and limitations of GIS technology. GIS provides significant advances in how we manage and analyze mapped data. It rapidly and tirelessly allows us to assemble detailed spatial information. GIS also allows us to incorporate more sophisticated and realistic interpretations of the landscape. It doesn’t, however, provide an artificial intelligence for land use decision making. GIS technology greatly enhances our decision-making capabilities, but it does not replace them.”

In this pointed article, Berry focuses on a point important to the use of GIS in this type of problem-solving that can be applied to the interface issue: GIS is a powerful tool to analyze and manage information, but will not itself make decisions. It is the fire managers and elected officials who have the final say.
2.3.3 Wildfire and GIS

Quantifying and Mapping Wildfire Hazard

In recent years, some state agencies have used environmental factors to delineate and map fire hazard zones in wildland/urban interface and intermix areas. The system used in California incorporates weighted values of fuels, topography (slope classes) and frequency of critical fire weather (Helm et al., 1973). Utah has used a similar system, and added a factor for response time from the nearest fire station. The hazard mapping in Utah is directly tied to subdivision regulations (State of Utah DNR, 1978).

The Colorado State Forest Service mapped wildfire hazards for each county with interface problems, and has used these maps for the zoning and planning of subdivisions. Areas were mapped into "fire severity zones" based on vegetation and slope (Groves, 1987). Map information included identification of topographic features that influence fire spread (chimneys, V-shaped valleys, and saddles), slopes greater than 30% (the point at which the rate of fire spread doubles relative to flat ground), tree density, ecosystem types, and fuelbreak locations (Dennis, 1983).

Fischer (1981) produced hazard maps for Missoula County and surrounding areas. These maps were based on standard 1:24,000 topographic maps, and delineated fire hazard zones into five categories based on potential fire behavior. However, these maps have not been published and are not currently in wide use for planning or mitigation programs. Their primary use has been for determining dispatch levels for wildland fires.

As early as 1978, various computer programs that were forerunners to a modern GIS were in use to determine broad-area fire potential and prevention program needs (Burgan and Shasby, 1984; Doolittle, 1978). However, the application of a GIS to broad-area fire mapping as a management tool is a recent innovation.

A recent paper discusses the development of a GIS for the spatial display of fire behavior
information. A network of remote weather sensing stations integrated current weather data, fuel maps, and topographic data, through the Canadian Forest Fire Danger Rating System (CFFDRS; CFS, 1987), into displays of spatial fire behavior information at a resolution of 1 hectare (2.47 acres). The hazard maps included information about the predicted head-fire rate of spread and crown fire potential (Feunkes et al., 1990).

A similar undertaking combined the elements of a forest resource inventory system, a fire behavior prediction system (CFFDRS) and fire suppression resource data into a comprehensive fire management modeling system. The resulting information and analysis system (1) provides a spatial display of the current fire hazard and resources at risk and (2) serves as a fire suppression resource allocation and location tracking system for modeling allocation and dispatch of suppression forces (Lee, 1990).

**Static and Temporal Analysis of Hazard**

Hirsch (1994) described two different means by which to display wildfire hazard with a GIS. Both methods use a fire behavior prediction system and GIS-based map layers of topography and fuel types. The first, used in this study, is somewhat of a "snapshot in time" in that it displays the potential fire behavior based on a specific set of weather conditions. This type of modeling is suited for assessing the hazard on a given day for a specific set of weather conditions.

The second type of hazard analysis is a probabilistic model. The user first must compile historic weather data for a given period of time. Then the predicted fire behavior is determined as above, but for every day in the weather database. The final GIS display shows a frequency distribution of the probability (or number of days) that a certain fire behavior parameter (such as intensity or rate of spread) exceeds a certain threshold value. This type of hazard analysis is more difficult to conduct due to the number of fire behavior computations and the amount of historic weather data needed. However, it is more useful for making management decisions, and lends itself better to combining with risk
(ignition probability) for an overall rating of the fire problem in an area (Hirsch, 1994).

Spatial Modeling of Fire Behavior

"Fire management is a spatial problem. The essential questions relate to when, where, and how many resources should be distributed across the landscape. These questions can only be answered on the basis of prediction: prediction of fire weather, fire danger, fire occurrence, and fire behavior.... The problem, then, is to be able to transform vast amounts of dynamic spatial and temporal data on weather, fuels, and topography into usable information that can be assimilated easily and rapidly by the fire managers." (Feunkes et al., 1990)

Wildfire growth is a spatial phenomenon, and presuppression planning could be augmented by modeling fire growth from a line source ignition in a variety of topography types. Using a GIS this way would enhance presuppression planning, and provide information for strategic placement of resources on a wildfire. This would be particularly useful for preparing daily operations and contingency planning on large wildfires.

A GIS can be used to model the spread and expected behavior of a wildfire in high-risk areas from a point-source ignition using recently developed methods for predicting fire spread from point source ignitions (McAlpine, 1990) and a spatially explicit fire spread model such as FARSITE (Finney and Andrews, 1994). This provides a means of assessing fire control issues for incipient wildfires.

New technology developments combine the fire behavior mapping and spatial analysis features of a GIS with components of the BEHAVE model. Several of these integrate Rothermel’s fire behavior prediction model (Rothermel, 1972) with the spatial analysis features of a raster-based GIS:

1. The recently-developed FARSITE (Fire Area Simulator) model (Finney and Andrews, 1994) incorporates the BEHAVE model with a raster-based GIS. This model uses Huygen’s wave-front principle as the fire perimeter propagation algorithm (Knight and Coleman, 1993). It integrates tabular input for weather and fuel bed complex parameters, raster-based GIS map layers for fuel models and topography, and Rothermel’s fire spread model (Rothermel, 1972). Using the wave-front principle, each point on the fire perimeter propagates relatively independently of its neighbors.
as a small ellipse, dependent almost entirely on the local fuel, topography, and weather variables. The collective envelope of these ellipses then described the new fire perimeter (Knight and Coleman, 1993). Thus, it is now possible to use GIS-derived information to simulate fire growth and characterize wildland fires in a spatially heterogeneous environment.

(2) The FIREMAP model (Vasconcelos, 1992) uses the DIRECT component of the BEHAVE system (Andrews, 1986) to model fire spread. Input into the model is in the form of raster-based slope, fuels, wind speed/direction, and moisture map layers. The actual fire spread modeling is done by means of a cell-to-cell propagation algorithm that determines the fire growth in the direction of maximum spread. The FIREMAP model is limited in its capabilities, and has not been used on a large scale to date.

(3) A “spatially-resolved” fire spread model demonstrated the ability of a GIS to account for heterogeneous terrain, vegetation, and weather (Kalabokidis et al., 1991).

**GIS and Defensible Space Analysis**

Fire managers may know intuitively that a house with a non-treated wood shake roof on a steep, heavily forested slope will need more defensible space than one with a fire-resistant roof, on flat ground, and surrounded by a green lawn. Past research has bolstered this through analysis of structure loss in actual wildfires (Howard, 1981; Davis, 1990).

What is not so clear is how much defensible space is needed, where it’s needed, and how it will impact a fire’s spread. Published guidelines provide generic recommendations, but it is up to the individual homeowner to determine how, where and how much defensible space is necessary based on specific local site characteristics. A GIS has capabilities that can provide site- and area-specific defensible space recommendations (clearance zones) through spatial analysis of local terrain (slope and aspect), surrounding vegetation, and structure characteristics. In Chapter 3, this is discussed in more detail.

**Defensible Space As a Spatial Issue**

As discussed earlier in this chapter, most published guidelines for defensible space include hazard mitigation zones. The first is the area in immediate proximity to structures, where more intensive fuel modifications are needed, at least 30 feet in all directions
from the structure. The second zone is an area beyond this where fuel modifications must reduce the intensity of a passing wildfire such that by the time the fire nears the structure, the fire's rate of spread, intensity, and other fire behavior characteristics do not pose an imminent threat to the structure. On flat terrain (less than 10% slope), this zone extends an additional 70 feet beyond the first 30-foot zone, providing a total of at least 100 feet of defensible space in all directions. However, most guidelines recommend increasing the distance of this zone from the house with increasing slope. The guidelines published by the Montana DSL (1993) are shown in Figure 2.3.3.

![Defensible space recommendations for three slope classes](image)

**Figure 2.3.3.** Defensible space recommendations for three slope classes. Note that with increasing slope, the clearance distance downslope increases while it remains the same uphill and cross-slope (Adapted from Montana DSL, 1993).

Similarly, a publication by the state of Colorado (Dennis, 1992) also provides specific clearance distances for both the first zone adjacent to the structure and the secondary
thinning zone (Figure 2.3.4). It also provides guidance for how to adjust the size of both zones for a wide range of slope values (Figure 2.3.5).

Figure 2.3.4. Defensible space recommendations for forested property. These guidelines include three zones of fire safety surrounding a homesite or subdivision: Traditional forest management activities (Zone 3), transitional zone (Zone 2), and intensive hazard mitigation (Zone 1). From Dennis, 1992.

Figure 2.3.5. Recommendations for defensible space distances by slope direction and degree of slope. The slope of the homesite is first located on the Y axis (20% in this example). By following this value horizontally to the right until it intercepts one of the curved lines, then moving vertically downward, one can determine the amount of defensible space needed on all sides of a home (adapted from Dennis, 1992).
**Risk and Spatial Risk**

*Risk* is any potential ignition source that can start a wildfire, and is broadly broken down into two categories — human-caused and natural (usually lightning). Risk is distinctly different from hazard; risk denotes the likelihood of an ignition, and hazard represents the relative flammability of the fuels (potential fire behavior, given an ignition). Risk is an important element of the interface fire problem; without ignitions, there are no fires, and the hazard level (and hazard mitigation issues) become irrelevant.

Ignitions are, however, a "given" in fire-adapted ecosystems. That is why understanding the nature of risk in an area is an important companion to hazard analysis. Knowing the distribution and cause of various levels of risk in an area allows fire managers to develop more focused hazard mitigation, fire prevention, and public awareness programs. Risk sources fall into two broad classifications -- lightning and human.

Recent research into the biophysical factors related to lightning-caused ignitions have not produced conclusive results (Skinner, 1992). Many historical records of lightning fires indicate that there are probably characteristics of vegetation, topography, and seasonal weather patterns that influence the spatial distribution of lightning strikes and resulting fires. It is not unreasonable to expect that a GIS could be used to derive a mathematical model to assess lightning-caused fire risk. However, there are some factors that have made this an elusive goal. "Holdover" fires often smolder in dead trees and duff and are not detected until several days or more after a lightning strike. This makes it difficult to correlate lightning occurrences with actual resulting fires. Also, the interaction of topography and weather patterns influences the distribution of vegetation, regional weather patterns, and localized "microclimate."

As will be shown later in this thesis, human-caused ignitions have a very different spatial distribution than lightning fires. Human-caused risk is particularly important in interface
areas, as human-caused fires are associated with human activities (Vega-Garcia, 1993). This will be discussed for Missoula County in Chapter 3. Human-caused risk sources include fireworks, matches, campfires, arsonists, debris burning, and vehicle malfunctions (especially brakes) along transportation corridors. Standardized inputs into fire prevention planning generally assign a higher risk factor for areas characterized by high levels of human activities (USFS, 1992; DeGrosky, 1989).

People living in interface areas generally have an awareness and perception of risk that is in stark contrast to reality. One study in particular examined the perceptions of interface residents in regard to the general fire problem and the probability of a fire impacting them. People who had lived in an area for some time generally felt there was a more serious fire problem than those who had just moved there. However, people living in communities recently impacted by a wildfire generally felt there was less of a threat than those living in a community not recently impacted (Gardner and Cortner, 1986).

**Spatial risk** is a measure of expected fire occurrence over an area. It is a means of quantifying the probability of an unwanted event (e.g., wildfire) occurring in a specific place and time. If one or more wildfires started in a particular land area with a certain set of biophysical characteristics, it is likely that wildfires can also be expected to occur in the future, with a certain probability, wherever the same set of environmental conditions existed (Phillips, 1978).

Doolittle (1978) found that once hazard and fire occurrence information was assembled and mapped, fires could be seen to occur in distinct clusters. Problem areas tended to have distinct, unique characteristics that lent a degree of predictability. Focusing upon these problem areas rather than jurisdictional or administrative units allowed for more effective utilization of often scarce prevention resources, and the results of prevention efforts were far more evident; by evaluating fire occurrence data in comparison to the
specific causes of fires, existing risk sources are addressed more effectively. This also
would allow fire managers to devise strategies for managing wildfire risk that may ac-
company future residential development in similar areas.

Spatial risk analysis would provide needed information to fire managers such as where
and in what numbers human-caused fires can be expected to occur in the future, how
these fires relate to the resource values protected, what human activity can be expected to
cause those fires, and the effectiveness of fire prevention in changing those expectations
(Phillips, 1978). A GIS provides a tool for this, allowing fire occurrence information to
be examined in relation to features, traits, and peculiarities of an area -- any of the infor-
mation from the various map layers. It permits one to examine and characterize the
pattern of fire occurrence in relation to geographic features and information such as
roads, population centers, and land use. Predicting past fire occurrence as a function of
biophysical traits of an area would allow one to characterize historic fire risk in interface
areas, and ultimately develop a predictive model to project the impact of new or proposed
residential developments on fire occurrence.

**Jurisdictional Issues and Protection Policies -- "Who's On First?"**

In interface areas, the collective wildland and structural fire protection jurisdictions often
are a tangle of jurisdictional boundaries. Homes are scattered across overlapping wild-
land and structural jurisdictions, areas with only wildland fire protection, and areas with
no existing fire protection of any kind.

Boundaries themselves are not always easily changed; even with the best of mutual aid
systems, knowing “who’s on first” is important. Agencies have specific and divergent
fire protection responsibilities and capabilities, and it is important to understand and
contend with these differences ahead of time. A GIS analysis of the nature of jurisdic-
tions and protection responsibilities in an area can provide needed answers.
While mutual aid agreements are an effective means of getting initial attack resources to a fire quickly, cost and liability issues are a different matter. In 1991, the LP Mill fire near the Rattlesnake Valley started as a structure fire in a rural fire district (Jahrig, 1991; see Figure 2.2.2). It later spread to an adjacent field and threatened to burn across a hillside having no fire protection and into four different combinations of jurisdictions in the Rattlesnake Valley. After the fire, determining which protection agency was responsible for what suppression costs quickly became quite complicated; a GIS would not have provided all the answers, but would have clarified at least the boundary and jurisdictional issues.

A GIS also provides a tool for assessing potential impacts of large, uncontrollable "disaster" fires. Wildfires have little regard for jurisdictional boundaries, and it is essential to be prepared for multi-jurisdictional incidents. Using overlays of historic large fires and jurisdictional boundaries as mock incidents, a GIS can show just what types of multi-agency complications could realistically arise. Possible organizational complications can be remedied before they are actually encountered in an emergency situation.
CHAPTER 3.

METHODS

"The relative importance of [data] files depends on their cost in terms of the human effort needed to regenerate them."
-- T. A. Dolotta; source unknown

3.1 STUDY AREA BOUNDARIES

This section describes the location and boundaries of each study area, and the derivation of the baseline layers. Section 3.2 then provides a descriptive history of the data sources and history for each layer of each dataset (MSLACO and RATTLE2). Information sources, levels of resolution, and any special processing used to derive each layer are outlined. Appendices F (Missoula County) and G (Rattlesnake Valley) serve as general guides to the layers contained within the GIS maps. These appendices outline the types of information on each vector and raster (surface and polygon) level, what the original sources of data were, and the date of the most recent revision of data for each level.

Many of the layers in the RATTLE2 map were similar to the MSLACO map. Some were taken directly from the MSLACO map -- such as large fire perimeters, and local jurisdictional boundaries. Where this occurred, it is indicated in the “Sources” column.

3.1.1 Study Area Locations and Boundaries

The two base maps and data sets used for the analyses are referenced in this chapter by their original file names -- RATTLE2 (the Rattlesnake Valley) and MSLACO (Missoula County). At times, each was split into sub-maps containing just a few layers each. This facilitated some of the analyses that required a great deal of free hard disk space. When the analyses were completed, all the new layers produced were merged back into the parent maps, RATTLE2 or MSLACO.
The MSLACO dataset encompassed the entire area of Missoula County, MT. The location of Missoula County is shown in Figure 3.1.1.

The Rattlesnake Valley lies entirely within Missoula County, north of downtown Missoula. The first GIS dataset for the Rattlesnake was named RATTLE1, and encompassed a 7½' by 7½' area. RATTLE1 was created in April, 1990, and later reduced in extent to include only the Rattlesnake Creek drainage; the new, smaller map was named RATTLE2. Figure 3.1.2 shows the boundaries of each of these datasets and their loca-
tions in relation to the Missoula County boundary. RATTLE2 was the map used for all the analyses in this study. Both maps are discussed further later in this chapter. Tables 3.1.1 and 3.1.2 describe the boundaries of RATTLE1 and RATTLE2.

Table 3.1.1. Map extents for RATTLE1, the initial map for the Rattlesnake Valley.

<table>
<thead>
<tr>
<th>Corner</th>
<th>Latitude, ° North</th>
<th>Longitude, ° West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>46:57:30.00</td>
<td>114:02:30.00</td>
</tr>
<tr>
<td>Northeast</td>
<td>46:57:30.00</td>
<td>113:55:00.00</td>
</tr>
<tr>
<td>Southeast</td>
<td>46:50:00.00</td>
<td>113:55:00.00</td>
</tr>
<tr>
<td>Southwest</td>
<td>46:50:00.00</td>
<td>114:02:30.00</td>
</tr>
</tbody>
</table>

Table 3.1.2. Map extents for RATTLE2, the final working map for the Rattlesnake Valley.

<table>
<thead>
<tr>
<th>Boundary Line</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>46:57:30° north, from the west boundary (100 ft. west of Grant Cr.) to the east boundary.</td>
</tr>
<tr>
<td>East</td>
<td>113:55:00° east</td>
</tr>
<tr>
<td>South</td>
<td>100 feet south of the south bank of the Clark Fork River to the south</td>
</tr>
<tr>
<td>West</td>
<td>100 feet to the west of Grant Creek to the west. Where this line crosses the original RATTLE1 boundary at 114:02:30° west, the boundary follows that longitude to the south boundary.</td>
</tr>
</tbody>
</table>

3.1.2 Baseline Layers -- Boundaries and PLSS

The first layers produced for MSLACO were the county boundary and PLSS layers. The actual legal description of the Missoula County boundary is given in Appendix H. The boundary and PLSS lines were each digitized from 1:100,000 mylar maps obtained from the U.S. Geological Survey. Map names and detailed map information are shown in Table 3.1.3. These maps were also used to verify information from other sources, primarily the location of major features such as powerlines, hydrography, and roads. PLSS lines for RATTLE2 were digitized from maps described in Table 3.1.4. For both

Table 3.1.3 USGS 1:100,000 scale mylar maps used for constructing initial base map layers for MSLACO.

<table>
<thead>
<tr>
<th>Map Name</th>
<th>USGS Reference No.</th>
<th>USGS Revision Date</th>
<th>Map Extent (Latitude-°N/Longitude-°W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missoula E., MT</td>
<td>46113-E1-MT-100</td>
<td>1984</td>
<td>46:30/113:00; 46:30/114:00; 47:00/113:00; 47:00/114:00</td>
</tr>
<tr>
<td>Missoula W., MT</td>
<td>N4630-W11400/30x60</td>
<td>1981</td>
<td>46:30/114:00; 46:30/115:00; 47:00/114:00; 47:00/115:00</td>
</tr>
<tr>
<td>Plains, MT</td>
<td>N4700-W11400/30x60</td>
<td>1980</td>
<td>47:00/114:00; 47:00/115:00; 47:30/114:00; 47:30/115:00</td>
</tr>
<tr>
<td>Seeley Lake, MT</td>
<td>N4700-W11300/30x60</td>
<td>1979</td>
<td>47:00/113:00; 47:00/114:00; 47:30/113:00; 47:30/114:00</td>
</tr>
<tr>
<td>Swan Peak, MT</td>
<td>47113-E1-TM-100</td>
<td>1988</td>
<td>47:30/113:00; 47:30/114:00; 48:00/113:00; 48:00/114:00</td>
</tr>
</tbody>
</table>
datasets, the PLSS layer was created at the same time as the study area boundary.

**Rattlesnake Valley**

The initial working map (RATTLE1), used for assembling the base layers, was a simple rectangle with the corner coordinates as described in Table 3.1.1. The corners for the RATTLE1 area were delineated from USGS 1:24,000 scale mylar maps (Table 3.1.4).

<table>
<thead>
<tr>
<th>Quadrangle</th>
<th>USGS Map Revision Date</th>
<th>Media</th>
<th>Map Extent (Latitude-&quot;N/Longitude-&quot;W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NW Missoula</td>
<td>1964/1978</td>
<td>Mylar</td>
<td>114:07:30/46:52:30; 114:07:30/47:00:00; 114:00:00/47:00:00; 114:00:00/46:52:30</td>
</tr>
<tr>
<td>NE Missoula</td>
<td>1964/1978</td>
<td>Paper</td>
<td>114:07:30/46:52:30; 114:07:30/47:00:00; 114:00:00/47:00:00; 114:00:00/46:52:30</td>
</tr>
<tr>
<td>SW Missoula</td>
<td>1964/1978</td>
<td>Mylar</td>
<td>114:07:30/46:45:00; 114:07:30/46:52:30; 114:00:00/46:52:30; 114:00:00/46:45:00</td>
</tr>
<tr>
<td>SE Missoula</td>
<td>1964/1978</td>
<td>Mylar</td>
<td>114:00:00/46:45:00; 114:00:00/46:52:30; 113:52:30/46:52:30; 113:52:30/46:45:00</td>
</tr>
</tbody>
</table>

*Original map date 1964; photorevised 1978.

The final study area boundaries (RATTLE2) were clipped from the RATTLE1 map. The north and east boundaries remained along the original lat/long-based boundaries of RATTLE1. The east and south boundaries were modified to limit the map area to the Rattlesnake valley, with some buffer into the adjacent drainages (Grant Creek to the west, East Missoula/Marshall Canyon to the east). The south and east boundaries were derived from hydrography features by copying these features parallel to and 100 ft. from their existing locations (see Table 3.1.2). Hydrography features used in this process were digitized from 1:24,000 scale USGS topographic maps (Table 3.1.4).

### 3.2 DATASET ORGANIZATION

The following subsections describe the derivation of the baseline map layers for the MSLACO study area. An additional description of RATTLE2 data derivation is included where appropriate.
3.2.1 Roads

The initial road layer for MSLACO was imported into PAMAP (ver. 3.0; EPS, 1991) from 1:100,000 scale USGS digital line graph (DLG) data and clipped by county boundaries within the GIS. USGS map file names and areas covered by each are described in Appendix I; these are shown schematically in Figure 3.2.1.

Four separate DLG files were available for each map area:

PIPE & TRANSMISSION LINES
ROADS & TRAILS

HYDROGRAPHY
RAILROADS

Figure 3.2.1. USGS DLG file coverages used for the MSLACO map. Map names for each 30' block are shown, as well as the USGS reference numbers for each sub-map within a block.
DLG-derived roads were edited (roads added, deleted, or modified) based on information from other map sources:

- USGS 1:100,000 mylar maps (see “Baseline Maps” above for description and revision dates).

- Printouts from Champion International GIS (scale of approx. 1:110,000; obtained from Steve Hayes). NOTE: This GIS is now owned and managed by Plum Creek Timber Corporation. Revised 1991.

- U.S. Forest Service “Series B” maps (paper 7½’ quads, approx. 2½” per mile). Obtained from Marge Lubinski, Lolo N.F. Scale = 1:24,000. Revised 2/91.

- Missoula City and vicinity - edited from blueline map obtained through the City engineer’s office. Revised 5/92. Scale = 1:12,000.

Finally, the vector elements on the road layer were classified into six major categories based on surface type and travel limitations (Table 3.2.1). For this, the 1991 U.S. Forest Service Visitor Maps (Lolo N.F. East and West, and Flathead N.F., scale approx. 1:126,720) were used in conjunction with ground and aerial photo verification of many of the roads. Due to the temporary nature of many logging roads, and the rapid rate of new road construction accompanying commercial and residential development, this map layer is not 100% accurate. This layer served primarily as a reference for other map features and boundaries, and in creating corridors adjacent to the primary roads.

<table>
<thead>
<tr>
<th>Road Type</th>
<th>Surface Type</th>
<th>Probable Travel Speed</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate, 4-lane</td>
<td>Paved</td>
<td>65 mi/hr</td>
<td>Interstate 90</td>
</tr>
<tr>
<td>Highway, 2-lane</td>
<td>Paved</td>
<td>55 mi/hr</td>
<td>State Hwy. 200 State Hwy. 86</td>
</tr>
<tr>
<td>Arterial “collectors”, 2-</td>
<td>Paved</td>
<td>35-45 mi/hr</td>
<td>Reserve St. Brooks Ave. Mullan Rd.</td>
</tr>
<tr>
<td>or 4-lane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential/Commercial “feeders”</td>
<td>Paved</td>
<td>25-30 mi/hr</td>
<td>27th Ave.; Mount Ave. Higgins St.</td>
</tr>
<tr>
<td>Primary dirt/gravel</td>
<td>Maintained dirt or gravel</td>
<td>25-30 mi/hr</td>
<td>Snowbowl Rd. above Grant Cr. USFS Rd. 44 (Holland Lake) USFS Rd. 477 (Morrell Cr.) Petty Cr. Rd.</td>
</tr>
<tr>
<td>Secondary dirt/gravel</td>
<td>Maintained/unmaintained dirt or gravel</td>
<td>&lt;25 mi/hr</td>
<td>Altura Dr. (Upper Rattlesnake) USFS Rd. 5557 (Martin Pt.)</td>
</tr>
</tbody>
</table>
The same classification criteria were used for the Rattlesnake Valley (RATTLE2) map. Since the roads in the county map (MSLACO) were edited and digitized from small-scale maps (1:24,000 USFS and 1:12,000 City of Missoula), these were simply merged into the RATTLE2 map and clipped at the RATTLE2 area boundary.

3.2.2 Railroads and Powerlines
Railroad and powerline map layers for MSLACO were derived solely from 1:100,000 USGS digital line graph (DLG) files. The map blocks, numbers, and dates are identical to those described for the road layer DLGs above. For the Rattlesnake Valley, railroad and powerline map layers were digitized from 1:24,000 USGS maps. These are the same quadrangles used for other map layers (DEM, major roads) in the RATTLE2 map. Neither of the railroad or powerline layers was used in any actual analyses, but served as a baseline for delineation of political, jurisdictional, and other boundaries.

3.2.3 Hydrography
For MSLACO, 1:100,000 USGS DLG files were used as the initial source for all hydrography. Major rivers (Clark Fork, Bitterroot, Blackfoot, and Swan) were edited by digitizing from 1:24,000 scale USGS quadrangles (paper maps) for greater detail. Many of the larger lakes (Seeley, Placid, Salmon) were also edited by digitizing from these 1:24,000 scale maps.

For the RATTLE2, hydrography was digitized from the 1:24,000 scale USGS quadrangles described in Table 3.2.1. Hydrant location and flow information was also included in RATTLE2. Originally, this study was to include an analysis of surface water supply from hydrants and draftable sources. However, it quickly became very complicated due to the difference in pump types that could potentially be used for drafting, and the variety of possible hose line and water supply system configurations for fire suppression operations. In the interest of limiting the scope of the study, this data was not used in the final analyses, but has been included in RATTLE2 for potential future use.
The position of each Rattlesnake Valley hydrant was physically located, discharge size(s) visually determined, and the location and discharge opening size(s) verified from MRFD and MFD maps and then digitized as a point feature on the map level. Specific hydrant flow and pressure data were obtained from the Missoula Rural Fire District flow test records (April, 1990) and Missoula Fire Department flow tests (February 9, 1992).

3.2.4 Digital Elevation Model (DEM)

Missoula County

Digital point data for the MSLACO DEM were obtained from USGS 1:250,000 data. This data was 3 arc-second, Type A, produced by the U.S. Defense Mapping Agency (DMA). It was obtained in tape format, transferred to the PC, and imported into PAMAP (ver 3.0; EPS, 1991). Since only general terrain features were needed, primarily for fire behavior modeling, the resolution and accuracy of this data was more than sufficient. Four USGS DMA digital elevation data files were incorporated into the MSLACO DEM. Table 3.2.2 provides more detailed information about each of these files.

The DEM resolution was 209 ft. (approx. 64 meters), which resulted in an area of approximately one acre per pixel. In defining map resolution (pixel size) in PAMAP, only whole integers can be used, so a pixel size of 209 ft. x 209 ft. was chosen. The actual dimensions of a one-acre pixel would be 208.71 ft²; therefore, each 209 x 209 ft. pixel in the MSLACO map has an true area of 1.003 acres.

This provided adequate resolution for fire behavior modeling, its primary use, and was

<table>
<thead>
<tr>
<th>Map Name</th>
<th>Date</th>
<th>Description</th>
<th>UTM Zone</th>
<th>Map Extent (Latitude-°N/Longitude-°W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butte-W (MT)</td>
<td>1978</td>
<td>Type A, 3 arc-sec.</td>
<td>12</td>
<td>46:00/114:00; 47:00/114:00; 47:00/113:00; 46:00/113:00</td>
</tr>
<tr>
<td>Chouteau-W (MT)</td>
<td>1978</td>
<td>Type A, 3 arc-sec.</td>
<td>12</td>
<td>47:00/114:00; 48:00/114:00; 48:00/113:00; 47:00/113:00</td>
</tr>
<tr>
<td>Hamilton-E (MT, ID)</td>
<td>1978</td>
<td>Type A, 3 arc-sec.</td>
<td>11</td>
<td>46:00/115:00; 47:00/115:00; 47:00/114:00; 46:00/114:00</td>
</tr>
<tr>
<td>Wallace East (MT)</td>
<td>1978</td>
<td>Type A, 3 arc-sec.</td>
<td>11</td>
<td>47:00/115:00; 48:00/115:00; 48:00/114:00; 47:00/114:00</td>
</tr>
</tbody>
</table>
within PAMAP's recommended limits for interpolation between elevation points -- 2/3 of the minimum spacing between the input data values (EPS, 1991). Other raster layers from outside sources (such as the vegetation layer) were re-sampled to this resolution. This provided internal consistency and allowed for analysis between all raster layers.

PAMAP provides three interpolation methods for creating a DEM. The "surface fit" method (TOPOGRAPHER module of PAMAP) was used to produce the MSLACO DEM. "Surface fit" is the recommended method for 3-d point data such as the DMA data used for the MSLACO DEM. The surface fit method fits a polynomial surface to the closest data points and evaluates the surface at the point being interpolated. The original z-values are not necessarily preserved in the final DEM due to the polynomial smoothing. The "finite difference" method in PAMAP does preserve the original z-values, but can be used only for contour elevation data, not point data such as the DMA data (EPS, 1991). However, since this DEM was to be used for fire behavior modeling, the accurate portrayal of general terrain features, rather than exact preservation of original elevation values, was the primary consideration.

The "power of distance" parameter in the surface fit method determines the influence a data point has on a particular pixel being interpolated. The higher the power of distance, the less influence, since the influence of the input elevation points is inversely proportional to the size of the distance power used (EPS, 1991). For the MSLACO DEM, a power of distance of 3 was used to provide some smoothing but avoid over-generalization of terrain features. The scan radius -- the distance from a pixel the interpolation algorithm searches for known data points -- was 350 ft. This allowed the interpolation algorithm to consider a minimum of several data points, rather than a single data point, in determining each pixel's value.

**Rattlesnake Valley**

For the RATTLE2 map, the type of analyses planned called for very accurate elevation
data. This was primarily driven by the need to accurately portray terrain in the vicinity of individual houses. Therefore, the DEM data for this map was input by digitizing 3-d contour lines from 1:24,000 scale mylar USGS topographic maps. The maps used were the quadrangles indicated in Table 3.1.4, and the elevation contour interval was 20 feet.

The “surface fit” method could not be used to create the RATTLE2 DEM due to the large number of data points in the digitized contour lines. The “finite difference” algorithm was chosen for two reasons: it is the most appropriate algorithm for contour data, and it preserves the original elevation values (EPS, 1991). The finite difference method "... is a repeated smoothing technique using a series of iterations over a surface. The technique can be visualized as somewhat like taking a pegboard filled with pegs of different heights and fixing a rubber sheet to the peg tops so that it is stretched taut over the pegs. The values of the input data points are not modified but the values of points in between the input data points are. The finite difference method is suitable for contour (trend) data only (EPS, 1991)."

The pixel size used for this DEM, as well as other raster layers in the RATTLE2 map, was 15 feet. This provided the level of resolution necessary for terrain-implicit analysis (fire behavior, defensible space) of individual homesites. There is a great degree of variability in the horizontal spacing of contour lines -- as little as 20 ft. in steep terrain and as much as 1700 ft. on the valley floor. The “minimum spacing of data points,” literally interpreted, then becomes the distance between data points on a given contour line. This ranged from approx. 15-60 ft.

3.2.5 Slope and Aspect

Slope and aspect maps for both study areas were derived from the DEM using the TOPOGRAPHER module of PAMAP. "Flat" areas in the aspect map were defined as any areas with a slope less than 5%. In the slope and aspect derivation from the DEM, moderate smoothing was achieved using a pixel displacement value of 2. In order to use
these layers in an overlay with fuels (for the fire behavior mapping), they were converted to polygon raster layers. This was accomplished as described below.

**Thresholding Surface Values**

Slope maps were classified into 10 percent classes up to 100%. Slope values above 100% were placed into a single class since the BEHAVE fire behavior model does not accept slope input values greater than this. Aspect maps were classified into five groups based on the following compass directions:

<table>
<thead>
<tr>
<th>Azimuth</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>315-360°, 0-45°</td>
<td>North</td>
</tr>
<tr>
<td>45-135°</td>
<td>East</td>
</tr>
<tr>
<td>135-225°</td>
<td>South</td>
</tr>
<tr>
<td>225-315°</td>
<td>West</td>
</tr>
<tr>
<td>&lt;5% slope</td>
<td>Flat</td>
</tr>
</tbody>
</table>

**Conversion to Polygon Layers and Generalization of Classes**

"Stray" pixels presented a problem in that their individual areas were quite small compared to the total map areas, yet they would result in a quite large number of polygons when the thresholded surface covers were converted to polygon layers. These stray pixels were removed by a combination of filtering the thresholded surface covers, and removing all polygons less than a chosen size after surface-to-polygon conversion.

The size of stray pixel groups/polygons to be merged with neighboring polygons, though somewhat arbitrary, was ultimately based on fire management guidelines -- the size classifications used to designate initial vs. extended attack fires. "Initial attack" fires are those that do not normally present serious problems and are controllable by the first arriving crews; these fires are generally less than one acre. "Extended attack" fires are those that do not necessarily present serious control problems, but may take additional resources or time to control. These are typically less than 10 acres (NWCG, 1989).

In the Rattlesnake Valley, small fires that can be quickly controlled ordinarily do not
pose a major threat to homes, so a polygon size of one acre was used as the largest area to be merged with neighboring polygons. For the RATTLE2 map, "stray" pixels were not a great problem. The thematic surface cover for slope and aspect were converted directly into a polygon layer and polygons with areas less than one acre merged with the predominant adjacent polygon.

At the county level, fires in remote or rural areas are often not readily accessible and often grow beyond one acre in size, though do not usually escape initial/extended attack. Those that grow larger than 10 acres often present more serious control problems, especially in areas with heavy fuel loadings. Therefore, a cutoff value of 10 acres (10 pixels) was chosen as the largest polygon area to be merged with neighboring polygons.

In the MSLACO map, the number of stray pixels was great enough to cause a serious problem in converting the thresholded surface layers directly into polygon layers. Therefore, the additional initial step of filtering the thresholded surface layers was done to eliminate excessive "stray" pixels. Filtering was done using a 5x5 pixel window. Each filtered thematic surface was then converted into a polygon layer, and polygons 10 acres or less were merged with the predominant neighboring polygon.

3.2.6 Fire Protection Jurisdictional Boundaries

Fire protection entities were classified into two general categories — wildland agencies and fire service organizations (FSOs). Wildland agencies include state or federal organizations whose primary mission is to provide wildland fire protection. In Missoula County, these are the Montana Department of State Lands (DSL), the U.S. Forest Service (USFS), and the Bureau of Indian Affairs (BIA). Although they may opt to provide structure protection (limited to exterior treatment of a building), they do not perform structural fire suppression, which includes interior fire attack. Note that due to exchanges in protection areas, and contracted protection in some areas, the wildland agency fire protection jurisdictional boundaries in most cases do not conform strictly to land
ownership or administrative boundaries of each agency.

**Fire Service Organizations (FSO)**

A blue-line map obtained from Missoula County Surveyor’s Office was used as a starting point for the MSLACO map. The Surveyor’s Office produced this map by enlarging a USFS “Visitor Map” (scale = 1:126,720) to a scale of approx. 1:60,000 and adding fire protection boundaries. The lines indicating FSO boundaries were quite wide (up to 0.2”) and in some cases did not clearly indicate what natural features or existing boundaries they were intended to follow.

The boundaries on this baseline map were digitized into a temporary working layer in the GIS for use as a rough starting point. Additional lines were added, or corrections made, based on information obtained from the County, maps from each individual FSO, or other sources as noted. Lines were made coincident, where appropriate, with features located on other vector levels: PLSS section lines (or interpolated quarter-quarter section lines), hydrography, roads, railroads, and powerlines. This was done to maintain internal spatial accuracy and improve the accuracy of protection boundary locations from the original County Surveyor’s map. Individual FSO boundaries were updated as shown in Appendix J.

**Wildland Agencies**

All wildland agency jurisdictional boundaries followed other existing map lines (roads, PLSS lines) or geographic features (ridge lines, hydrographic features). These boundaries were added to the MSLACO map, using paper maps obtained from the USFS (Missoula District), MT DSL (Missoula Unit), MRFD, MFD, and BIA (Flathead Agency), as guides. Actual boundaries were digitized to coincide with the appropriate PLSS section lines, roads, and geographic features.

For the Rattlesnake Valley, the wildland and FSO jurisdictional boundary vector ele-
ments were simply merged into the RATTLE2 map from MSLACO and clipped at the
RATTLE2 study area boundaries. The maps from which wildland and FSO jurisdic-
tional boundaries were initially digitized in MSLACO were of sufficient resolution and
accuracy to allow for this.

3.2.7 Land Ownership
The MSLACO land ownership layer was classified into four categories, as shown in
Table 3.2.3. Land ownership boundaries and classifications were determined by infor-
mation provided in the 1:126,720 scale 1991 USFS "Visitor Maps" of the Lolo and
Flathead National Forests. Boundaries were entered and edited using PLSS (section and
quarter-quarter section lines), hydrography, and road layers as guides. All ownership
lines were coincident upon portions of these lines.

3.2.8 Population Density
Duane Lund at the Montana Natural Resource Information System (NRIS, Montana State
Library), kindly provided 1:100,000 scale DLG files of U.S. Census blocks and the
accompanying database for the 1990 U.S. Census for Missoula County. The line files

<table>
<thead>
<tr>
<th>Type of Ownership</th>
<th>Description</th>
<th>Inclusive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal</td>
<td>Federal land management agencies (govt.)</td>
<td>U.S. Forest Service</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bureau of Land Management</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bureau of Indian Affairs</td>
</tr>
<tr>
<td>State</td>
<td>State land management agencies (govt.)</td>
<td>Montana Dept. of State Lands*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Montana Dept. of Fish, Wildlife, and Parks</td>
</tr>
<tr>
<td>Private Industrial</td>
<td>Commercial Timberlands</td>
<td>Plum Creek</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Champion International**</td>
</tr>
<tr>
<td>Private Non-Industrial</td>
<td>Private land not wholly owned and solely used for commercial</td>
<td>Agricultural uses</td>
</tr>
<tr>
<td></td>
<td>timber production by a commercial timber company.</td>
<td>Residential Business</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Others, not classified</td>
</tr>
</tbody>
</table>

* Prior to 1995 fire protection for the State of Montana was a function of the Department of State Lands. Following
a re-organization in 1995, the fire protection function was placed under the Department of Natural Resources.

** Prior to 1993, there were two commercial timber corporations owning land in Missoula County -- Champion
International and Plum Creek Timber Co. In 1993, Plum Creek purchased all of the land owned by Champion and
became the sole owner of land in this classification in Missoula County.
and database tags from NRIS were in UTM zone 12 (NAD83) projection, “standard” DLG format. These were translated to the “optional” format using PC ARC/INFO, then imported into PAMAP. The database records and census block descriptions were contained in two separate databases. These were combined in FoxPro into one database. Attributes in the final database included the census tract and block numbers, total population in each block, and total population over age 18.

The DLG files obtained from NRIS were edited, where appropriate, to match road and hydrography lines in the MSLACO map. This was done to (1) maintain internal spatial integrity between map layers, and (2) to reflect the higher degree of accuracy contained in the other map layers. The initial “raw” 1990 census map is on level 54; the final edited population density map layer (vector and polygon layers, and database) is on level 55 in MSLACO (see Appendix F).

3.2.9 Fire History

Large Fire History

This layer features the perimeters of fires 10 acres and greater (extended attack designation and larger; NWCG, 1989) that have occurred in Missoula County between 1889 and 1991. Maps of these perimeters were obtained from a variety of sources, outlined in Table 3.2.4. Where two or more fire perimeters overlapped, they were placed onto one of three separate map layers to permit each fire to be individually represented. These three layers were overlaid into one master layer that contained information about each individual fire, even where the perimeters overlapped.

Ten year fire occurrence, 1981 - 1990

This information was vital to the risk analysis. Data was collected from each FSO and wildland agency in the county. Jon Skinner was very helpful for this very tedious part of the data collection. Ray Nelson of the Montana DSL had developed a PC-based data entry form for DSL’s annual fire reporting system, and was kind enough to provide us a
Table 3.2.4 Sources of large fire history data, 1889 - 1991; fire perimeters and occurrence information.

<table>
<thead>
<tr>
<th>Source</th>
<th>Format</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. Forest Service (Jack Losensky)</td>
<td>1:126,720 scale blueline maps</td>
<td>These maps provided the majority of the information used, particularly prior to the 1980s. Lolo National Forest only.</td>
</tr>
<tr>
<td>U.S. Forest Service (Howard Roose)</td>
<td>Paper maps from incident reports</td>
<td>Recent fires (1980s and beyond); Lolo National Forest</td>
</tr>
<tr>
<td>Montana DSL (Paul May)</td>
<td>Paper maps from incident reports</td>
<td>Recent fires (late 1970s and beyond); Southwestern Land Office.</td>
</tr>
<tr>
<td>University of Montana, Wildlife Research Unit (Per Sandstrom)</td>
<td>Digital, in PAMAP (vector/database data)</td>
<td>For Swan Valley portion of Missoula County (Flathead National Forest, USFS, and Northwestern Land Office, DSL)</td>
</tr>
</tbody>
</table>

copy of this form, and ultimately DSL's fire records, for Missoula County for 1981-1990. Jon Skinner loaded this data form into a laptop PC and visited each fire service organization to collect the data. Where the location (PLSS) of a fire was in question, we consulted with fire department personnel and records to determine the location of these fires.

The USFS and BIA had this information in a computer database, but it was not readily convertible to a PC-based format. The Lolo National Forest (Verne Schwartz), Bitterroot National Forest (Leslie Anderson) and Flathead National Forest (Ted Richardson) provided printouts of the USFS fire records. The BIA, Flathead Agency, provided a printout of the BIA fire records. Jon Skinner entered all these into our database.

The final database contains all the available wildland fire incidence records for Missoula County from 1981-1990. There were some records missing from FSO logs; this was an unavoidable source of error. However, greater than 95% of all wildland fire incidents were included in the GIS database.

For RATTLE2, the fire records (historic large fires and 1981-1990 fires) from MSLACO were simply merged into the RATTLE2 map. Large fire perimeters were clipped at the RATTLE2 study area boundary.
3.2.10 Vegetation and IFSL Fuel Model Maps

Missoula County

The terms "fuel model" or "IFSL fuel model" used in this thesis both refer to the classification system whereby surface fuels are grouped into the 13 stylized models, developed by the USFS at the Intermountain Fire Sciences Laboratory in Missoula, MT (Anderson, 1982). These are based on the loading (tons/acre) of live and dead fuels in various vegetation types, and are designed specifically for surface fire behavior prediction with the BEHAVE model. IFSL fuel models are sometimes referenced in the literature by former terminology -- NFFL (Northern Forest Fire Laboratory) fuel models. NFFL and IFSL fuel models are identical. A description of fuel models is provided in Appendix K.

During the beginning phase of this study (1990-1991), the vegetation and fuel model layers for Missoula County presented a problem. 2,625 square miles would have been too great an area for anyone to classify vegetation from aerial photography, and there was not one single, comprehensive vegetation map for the entire county. Rather, each individual land management agency or corporation had produced a set of maps for their own management purposes, and specific to the lands they managed or administered. Satellite imagery (LANDSAT TM [Thematic Mapper]) was available for Missoula County, but would have required a level of expertise in image processing not possessed by the author, and many weeks of extensive ground-truthing.

Fortunately, a project was underway that ultimately provided a vegetation map suitable for fuels classification. The County of Missoula had started the process of putting together a GIS for rural planning purposes. Under a contract between GeoData Services and the County of Missoula, Ken Wall began assembling GIS map and data layers of Missoula County. For the vegetation layer, he worked with Pat O’Herren (Rural Planner for the County) to arrive at a list of vegetative classes that the County wanted in the vegetation layer (Appendix L).
Given this information, Ken Wall worked with Dr. Zhenkui Ma of the University of Montana to produce this layer from LANDSAT TM imagery (from August, 1991). Dr. Ma had extensive expertise in image classification and completed the work in several months. Ken Wall converted the final product into a format readable by PAMAP as a surface [raster] layer. Appendix M outlines how this map layer was produced. Finally, Pat O’Herren was kind enough to release the final vegetation layer in exchange for the derived hazard maps from this study.

Once merged into the MSLACO dataset, this layer was then filtered twice with a 3x3 window to remove single or small groups of “stray” pixels. Filtering parameters were adjusted to provide the least change in the larger areas of similar pixels, while providing for the maximum removal of “salt and pepper” pixels -- noise/replacement neighbors = 5/4 (first pass) and 5/5 (second pass). 1% of the pixels were modified in the first filtering, and less than 1% in the second.

From the description of each initial vegetation class, these classes were grouped into representative IFSL fuel models. Using a guide to fuel model classification developed by the USFS (Anderson, 1982), the final IFSL fuel model layer in MSLACO was then field-verified. This layer was plotted on paper, with road and hydrography features added for reference points, and fuel model classes visually confirmed at selected locations throughout the county, primarily those area in proximity to subdivisions and rural residential developments.

The MSLACO fuel model map was also compared to the RATTLE2 fuel model map (described below). In all cases, the LANDSAT-derived vegetation data was sufficient to provide satisfactorily detailed, accurate IFSL fuel model classes for fire behavior modeling. Finally, the resolution of the original map (30 meters) was transformed to reflect the resolution of MSLACO -- 209 feet.
**Rattlesnake Valley**

Due to the relatively small land area involved, and the need for very detailed vegetation mapping within developed areas, the vegetation mapping for the Rattlesnake Valley was done using aerial photography.

Boundaries of visually distinct vegetation types were delineated onto a 1:24,000 mylar map, based on 1989 aerial photo stereo pairs (color, 9"x9" photos, 7/89). Actual vegetation types and stand structures were determined through ground verification, with emphasis on the characteristics of vegetation that could potentially influence fire behavior. Thirty-two separate vegetation classes were delimited initially. These were then grouped into the stylized IFSL fuel models for fire behavior assessment.

### 3.2.11 House Locations -- Rattlesnake Valley

This data includes all house locations as of July, 1992. The Rattlesnake Valley continues to experience tremendous residential growth. Therefore, not all of the houses presently in the valley at the time this thesis was completed are included in this layer. However, since the vast majority of the new housing development is not in wildfire-prone areas, the impact on the analyses is negligible.

Individual houses were plotted on paper maps (scale approx. 1:10,000), and roof types determined for each, based on ground verification (via a “windshield survey”). Within the database, each house is identified as having either a flammable roof (wood shake) or fire-resistant roof (clay tile, metal, composition, fiberglass, etc.). Structures were generalized into two major house classes -- approx. 30'x40' for houses, and customized sizes to match the footprints of larger structures such as schools and apartment buildings. The exact size of each structure was not critical for the primary purpose, the defensible space analysis, providing that the size of rectangles used to show house locations was within a size range representative of most “average” houses.
Once each building had been placed into the map layer, the exact location and orientation of each house in relation to roads and terrain features was verified from aerial photos (7/89) obtained from the USFS, Lolo National Forest. Changes in the GIS map layer were made accordingly.

3.2.12. Road Distance Layer -- Missoula County

This layer depicts the continuous linear distance from major roads. All roads were used except secondary dirt roads. First, a surface cover was created from these roads; this was at a resolution of 209 ft. Then, a distance raster was generated using "Distance from Features."

3.3. SOFTWARE AND HARDWARE SYSTEMS

3.3.1. Software

The following programs were used in the compilation of map layers and databases, GIS analysis, and the final production of this thesis:

- **PAMAP GIS software.** Ver. 2.2, 3.0. and 4.0.
- **ARC/INFO PC.** Ver. 3.4.2
- **Foxpro DBMS software.** Ver. 1.0, 2.0, 2.5 (Windows)
- **SYSTAT statistical analysis software.** Ver. 5.0
- **CorelDRAW! Ver. 3.0 (Windows).** Graphics software for presentation graphics in this document.
- **LView (Windows).** "Shareware" graphics software for editing color schemes of bitmap graphics from raster map layers.
- **Paint Shop Pro.** "Shareware" bitmap graphics processing and editing program.

3.3.2. Hardware

A PC-Compatible computer system (Intel 80x86 CISC processor) was used for all data analyses and data acquisition and processing, except where indicated otherwise. A 486-33mhz system with 8Mb RAM was used initially (Gateway Computing). Later, this was upgraded to a Pentium-60 mhz system with 16 Mb RAM (custom-built by D. Herzberg of Missoula, MT).
CHAPTER 4.

VARIABLES AND SOURCES OF VARIATION

"The government are very keen on amassing statistics. They collect them, add them, raise them to the nth power, take the cube root, and prepare wonderful diagrams. But you must never forget that every one of these figures comes in the first instance from the village watchman, who just puts down what he damn well pleases."

-- Anonymous; quoted from Sir Josiah Stamp, Some Economic Factors in Modern Life (Quote obtained from Pilsworth, 1992)

Perhaps one of the more difficult aspects of describing this study has been recognizing and remaining cognizant of the limitations of a GIS as a spatial analysis tool. It can become far too easy to view it as a panacea for whatever planning and analytical woes we might be facing. In reality, like any tool, there are uses, abuses, and limitations of its usefulness.

4.1 SOURCES OF ERROR

This section focuses on the sources of error -- potential and actual -- that might have affected the outcome of the analyses. Although software and hardware issues are included, by far the most important is that of the data sources themselves.

4.1.1 Data Sources and Processing

Data Sources

One of the most important sources of error in this project was in rectifying data layers from a variety of sources, as was discussed in Chapter 3. Integrating maps digitized at different scales, and to different degrees of accuracy, inevitably brought inconsistencies to light. This was a concern in that spatial analyses are affected by map scale and accuracy. Where one data source was known to be reliable and accurate, it was used to correct others to the extent possible.
This was the case with roads. The roads and streets in the Missoula County map were initially derived from 1:100,000 USGS digital line graph (DLG) files. However, this vector layer underwent an extensive overhaul to improve its accuracy. In the Missoula area, most road segments were re-digitized from a current 1:12,000 scale map from the Missoula City Engineer's office. In most other parts of the county, similar editing or re-digitizing was done from the USFS “B-series” 1:24,000 scale maps. Once complete, this layer was certainly one of the most accurate, if not the most accurate, of any. Thus, it was used to add or correct political, jurisdictional, census, and other boundaries that were wholly or partially coincidental with roads.

The secondary vector layers used for this were the hydrography and Public Land Survey System (PLSS) layers. Like the roads, the major rivers and lakes in the hydrography layer were originally derived from 1:100,000 DLG files; the major rivers and lakes were then edited or re-digitized from 1:24,000 scale maps. These were important for some of the census blocks and jurisdictional boundaries. The PLSS (section) lines were initially digitized from 1:100,000 mylar maps and then edited in many areas from 1:24,000 USGS maps.

The resulting vector layers were very consistent spatially. However, considering the variety of digitizing scales included (1:100,000, 1:24,000, and 1:12,000), there is likely to be some error in plotted versus actual location of lines, which could affect area determinations where these lines were used to form polygons.

Data Resolution of the DEMs
The spatial resolution of data was a likely source of error in the initial map layers. The 1:250,000 scale (3 arc-second) USGS elevation data used for the Missoula County digital elevation model has been reported to be accurate by as much as +/- 30 feet. For as large an area as Missoula County, and considering the map resolution used (40m pixel size), this elevation data was quite adequate. The primary use of the
DEM was to produce a slope and aspect map for the fire behavior analyses; minor inaccuracies in elevation values would not have had an appreciable influence on the nature of these derived layers, and certainly not on the very weather-dependent fire behavior modeling.

For the Rattlesnake Valley DEM, the same holds true. While the actual elevation contour lines from 1:24,000 mylar maps provided an accurate source of input data, the type of interpolation used to form the DEM (finite difference) probably introduced some minor interpolation errors in the final slope and aspect maps used for fire behavior and defensible space analysis. Again, due to the way these layers were used in subsequent analyses, it is unlikely that any inherent or introduced error in the DEM would be noticeable or significant in the final derived layers (flame length, defensible space).

**Filtering of Surface Covers**

Several map layers were filtered to provide cartographic clarity, and to reduce the number of polygons produced from that layer. These included the slope, aspect, and vegetation surface layers.

Any time pixel values are changed from an actual value to one derived by “neighbor influence,” some inaccuracy results. The actual influence of “stray” pixels, if left unaltered, is minor considering the general influence of the local topography or surrounding vegetation. Of greater concern is the “wandering” of sharply defined boundaries that can occur with some filtering parameters. This was minimized by adjusting filtering conditions to achieve the maximum removal of noise pixels with minimal boundary drift.

**Missing Data**

This was an issue with the collection of 10-year fire occurrence data. A few fires
could not be included because of poor location descriptions. Fortunately, this amounted to a mere handful out of the total. Data for other fires were just plain missing; one FSO in particular did not have fire occurrence information for 2 of the ten years examined. This particular FSO did not have a high fire occurrence, but it nevertheless affected the overall accuracy of the fire occurrence data.

**Generalization in BEHAVE Model Inputs -- Bad Behavior**

Some of the inputs for the fire behavior modeling contained error introduced from generalization. Slope classes were lumped into 10% classes, and the maximum value of each class was used for input into the BEHAVE model. This would result in a slight over-prediction of fire intensity and spread rate. In addition, the BEHAVE model only accepts slope input up to 100%, so all slope values exceeding this were classified as “100%.” This would result in under-prediction of the same outputs. However, due to the limited residential development on 100% and greater slopes, this was not a great concern.

Likewise, aspect was broken down into only five classes (including “flat”), resulting in a substantial generalization of terrain directionality. However, the fine fuel moisture inputs into the BEHAVE model only consider the four primary aspects, so this could not be avoided.

Another source of error worth noting results from the used of very generalized fuel models. Using the IFSL fuel model system, all the vegetation in Missoula County is represented by only a handful of models. These models represent the real world very well in some cases, less so in others. Nevertheless, they limit the accuracy of the BEHAVE model. Although BEHAVE output is presented to two decimal places, it is probably only reliable within a single order of magnitude -- such as within a flame length class.
One particular vegetation class used to determine fuel models, "agricultural," includes several very diverse vegetation types — irrigated agriculture, dried grain or stubble, and grazing. These all can vary markedly in flammability and fuel loading during the year, and are thus not well represented by a standardized fuel model.

Perhaps the biggest and most erroneous generalization made was that of the weather inputs into the BEHAVE model. Weather conditions were assumed to be uniform over the entire county. In reality, this occurs seldom -- if ever. For the sake of simplicity, the fire behavior modeling in Chapter 5 does not account for local variability in weather. In addition, the direction of the wind is assumed to be uphill in all cases, which may result in over-prediction of fire spread and intensity in some cases.

Risk Factors
The spatial risk analysis was plagued with more difficulties than any other part of this project. Initially, it was the one analysis that did not yield conclusive results despite the intuitive relationship one could conclude in viewing the fire occurrence in relation to other geographic features. Demonstrating this relationship, though successful, was not as easy as initially supposed.

The difficulty in quantifying a strong relationship between human-caused fire occurrence and population density, distance from roads, or other layers can probably be attributed in part to several things:

- Missing fire occurrence data (as previously discussed)
- Coarse resolution of the quarter-quarter section fire location description. This limited the spatial resolution to about 40 acres. This was likely to be a greater problem where the population density varied greatly between adjacent, relatively small census blocks.
- Gross generalization introduced by converting the road distance and population density layers to quarter-quarter resolution. This reduced the ability to measure the proximity effects of roads and the influence of variations in population over small areas.
- Many of the census blocks, particularly those in interface areas, are quite large, and generalize the heterogeneous distribution of the population in each block over large areas.
- The 1990 census data is static; the actual population density is spatially dynamic, as is the occurrence of fires.
Much of this has been previously discussed in Chapter 5, but also bears noting here.

*Wildfire Semantics -- Classification and Reporting*

When is a wildfire not a wildfire? This has often been a subject of debate during the open burning season each year. A particular fire is reported as a wildfire if the person setting the fire does not have a valid burning permit, regardless of whether the fire is controlled or not; the same fire would not be reported as a wildfire if that person had a valid permit and the fire was under control. This can have a small but noticeable impact on the number of human-caused wildfires reported, particularly by rural fire districts -- who bear the brunt of human-caused fire occurrence.

A different but related issue involves the regional climate differences between the Missoula Valley and the Seeley-Swan Valley. In late spring, the Missoula Valley can be in "high" fire danger while there is still a continuous cover of snow on the ground at Seeley Lake and Condon. The Seeley-Swan Valley is normally cooler, moister, and has heavier and later snow cover than the Missoula Valley. However, the burn permit system is run on a county-wide basis. Once county-wide restrictions are in place due to high fire danger (in the Missoula Valley), even a warming fire set among snow-drifts at Seeley Lake could be classified as a "wildfire."

The information from fire reports does not always provide enough information to discern between restriction- or permit-related wildfires and those fires that are actually unwanted, out-of-control wildland fires. Therefore, the best that can be done, at least for this report, is to realize and document this concern.

A third situation is encountered in more urban settings. The fire reporting system currently used by fire departments in Missoula County is based on a national system known as NFIRS -- the National Fire Incident Reporting System. This system was designed primarily for reporting structure fires, but does include classification codes
for wildland fires. The NFIRS classifications for vegetation fires are broad, and
especially define wildfires as any fire burning in vegetation.

Thus, a firecracker that starts an ornamental juniper bush on fire, or a fire started in a
small vacant lot in a heavily urbanized area, are classified as wildfires -- and given
the same designation as a wildland fire burning through a large area of continuous
wildland vegetation. These "wildfires" are defined very generally, and one might at
first be tempted to dismiss these as not being "true" wildland fires. However, they
are actually important to document and classify with other wildfires in rural areas. As
has been previously discussed in this thesis, both risk and hazard are important in
defining the fire problems of an area. Risk without hazard (urban "wildfires") is as
important as hazard without risk (unpopulated areas) in describing the entire spec­
trum of wildfire situations in as large an area as Missoula County.

4.2 CONSTRAINTS OF THE ANALYSES

The limitations of the analyses fell into three major classes: hardware, software, and
intent of modeling tools. None are insurmountable barriers, but were notable factors
in this study. Some constraints were imposed for the sake of simplicity, others
resulted from mismatches in software and hardware capabilities and the size of data
sets.

4.2.1 Hardware

CPU (Central Processing Unit) and Memory

The primary difficulties attributable to hardware are limitations in processing speed,
memory, and hard disk capacity. Most of the initial map-building and analysis were
done on a 486-33 CISC (Complex Instruction Set Calculation) processor (Intel
x8086design), which proved adequate for most tasks. However, there were some
functions that were limited by the 8 megabytes of RAM (Random Access Memory) in
this machine. One could blame the problems on the large map size or the small machine size; either way, there was a disparity between needed and available resources. Fortunately, a similar machine with more RAM was available, and this machine was used for the few times more RAM was needed to complete a task.

*Disk Capacity*

The hard drive capacity became an increasing problem as the project grew. More raster layers, greater resolution in the raster layers permitted by better software, and bigger, more detailed databases all resulted in steadily increasing map file sizes. Eventually, the 200 MB hard drive that seemed so ample just two years before now was hopelessly limiting in the ability to store data or run necessary analyses. The solution was a combination of steadfast file management, splitting one large data set into several smaller ones, fewer-layered data sets, and storing files on the newly-installed local area network.

An example of a “single-use” data set is the one used for the spatial risk analysis. This data set included the entire county area, but contained only the map layers and data needed for the spatial risk analysis -- fire occurrence, population density, land ownership, and road proximity. This approach allowed for the “master” county map to be temporarily stored elsewhere while the analysis was being run, and also meant that less disk space was required to run the analysis.

As an alternative, the entire map set could be stored intact on a remote network drive and used as-is for all the analyses. This worked in most cases, but running the analyses on a remote drive was considerably slower than on a local drive.

**4.2.2 Software**

Certainly, there are limitations in the capabilities of all software. This was more the case in the early part of this project than the latter. The earlier versions of PAMAP
(ver. 2.2 and 3.0, both DOS versions) had limitations as to the maximum size of the pixel array in raster layers, as well as the number of polygons that could be contained in a polygon layer. This posed some difficulties in the overlays that would be necessary for the hazard analysis for Missoula County. However, there were a couple of bright sides to this. First, the lack of a good vegetation (fuel model) layer hindered this analysis for some time. By the time a high-quality vegetation layer became available, PAMAP ver. 4.0 (Microsoft Windows-based) had been released, with less restrictive limits as to the maximum resolution of raster layers.

Additionally, the same was true for the defensible space analysis. Many additional parameters were built into the corridor analysis functions in PAMAP in ver. 4.0, allowing for more versatility in the inputs to the proximity analysis.

4.2.3 Models

Limitations of the BEHAVE Model

The BEHAVE model has inherent limitations in its intended applications. In interpreting the fire behavior maps presented in Chapter 5, it is important to remember that the BEHAVE model was designed for predicting surface fire behavior only. Under dry, windy conditions, there is a strong probability of crown fire occurrence where a continuous coniferous overstory is present. When weather conditions bring about a transition from a surface fire to a crown fire, the BEHAVE model no longer applies.

A fuel model that demonstrates the extent of this dichotomy is that of IFSL fuel model 8, represented in Missoula County by extensive stands of lodgepole pine. Under even strong wind conditions, surface fire behavior is not usually extreme due to the typically low surface fuel loading in. However, crown fire potential can be great. In fact, crown fires often occur in this fuel model independent of surface fires.
The “benign” fuel model changes from a relatively innocuous surface fuel type to a more hazardous, elevated fuel bed (crowns) due to a shift in inputs (wind). At this point, the weather inputs to the BEHAVE model exceed the intended use of the model. BEHAVE does not presently predict crown fire behavior, although surface fire flame lengths over 11 feet do indicate the possibility of crown fire development.

**Defensible Space Modeling**

How much is enough? A defensible space representation around a structure is only as good as the underlying assumptions used to build such a space. As discussed previously, there is little discussion in any of the published guidelines as to why or how any of the minimum clearance distances were determined. At the present time, there is no quantitative, mathematical model for determining defensible space needs based on specific local conditions. However, the SIAM (Structure Ignition Assessment Model) under development by Cohen et al. (1991) promises to be of help in this area.

**The impact of flame length**

Surface fires can ignite structures through radiated heat, a direct function of fire intensity, and by firebrands, the production and transport of which is driven primarily by an interaction between fuels and wind. Which component of fire spread is actually more important, and how is it reliably quantified? This is not well described, nor is an effective means to assess each in relation to the defensibility or survivability of a structure. In order to improve the reliability of a GIS determination of defensible space needs, a solid, quantitative model of external structure ignition factors must be used.
CHAPTER 5.

ANALYSES AND DISCUSSION

"Why, sometimes I've believed as many as six impossible things before breakfast."
-- The White Queen; Alice Through the Looking-Glass (L. Carroll)

5.1. HAZARD ANALYSIS -- FIRE BEHAVIOR MAPPING

5.1.1. Background and Methodology

Wildfire hazard consists of three components: fuels, weather, and topography (NWCG, 1981). These are also the fundamental inputs to fire behavior models. Two of these, fuels and topography, are important map layers in both the MSLACO and the RATTLE2 data sets.

The BEHAVE fire behavior prediction model (Andrews, 1986) estimates surface fire behavior based on fuel, topography and weather inputs. It was chosen to spatially model potential fire behavior in this study -- fire intensity and rate of spread -- using fuel and topography inputs provided by the GIS.

Wildland fuels are classified either as live (herbaceous or woody) or dead. Diameter size classes for dead fuels, used by each of the 13 IFSL fuel models, are broken down according to the ranges shown in Table 5.1.1. These size classes are classified according to "timelag," or the amount of time it takes for that size class of fuel to gain or lose about 2/3 of its fuel mois-

<table>
<thead>
<tr>
<th>Timelag Class</th>
<th>Size Range (Dia., in.)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-hour</td>
<td>&lt; 0.25&quot;</td>
<td>Needles, leaves, cured grass and herbaceous plants, and fine dead stems.</td>
</tr>
<tr>
<td>10-hour</td>
<td>0.25&quot; - 1&quot;</td>
<td>Medium-size twigs, stems, small branches.</td>
</tr>
<tr>
<td>100-hour</td>
<td>1&quot; - 3&quot;</td>
<td>Larger tree branches.</td>
</tr>
<tr>
<td>1000-hour</td>
<td>3&quot; - 8&quot;</td>
<td>Small logs.</td>
</tr>
</tbody>
</table>
ture when subjected to a change in temperature or relative humidity. Each fuel model is classified by the loading (tons per acre) of each fuel size class.

Large woody fuels (> 3” diameter) do not have a major influence on the spread and intensity of a passing wildfire and are generally not considered when calculating outputs from the BEHAVE model. The fine fuels (1-hr. and 10-hr. timelag) have the greatest influence on a fire’s spread and intensity, and 1-hr. fuels are the most important of these.

Fuel moisture is a critical input into the BEHAVE model, and is largely a function of the fuel type and size class as described above. 1-Hr. timelag fuel moisture can be readily determined from a series of tables (NWCG, 1992). First, the “reference fuel moisture,” or starting value, is calculated from the temperature and relative humidity. Following the determination of the reference fuel moisture, a “fine fuel moisture content correction” must also be determined for the actual site conditions. This correction factor takes into account variations in fuel moisture due to the time of year, amount of shading, aspect, and degree of slope.

From these tables, 1-hr. fuel moistures can be estimated for a variety of conditions. For larger size classes (10-hr. and 100-hr. timelag classes), fuel moistures are measured directly by any of a variety of methods. As an alternative, 10-hr. fuel moistures are often estimated by simply adding 1% to the 1-hr. fuel moisture, and 100-hr. fuel moistures estimated by adding 2% to the 1-hr. fuel moisture (NWCG, 1992). The latter method was used in the fire behavior calculations in this analysis. Specific weather conditions and characteristics of individual IFSL fuel models were used together to compute the 1-hr. fuel reference moisture content for input into the fire behavior model.

5.1.2. Input GIS Map Layers

Topography

The digital elevation model (DEM) was the starting point for inputs to the hazard analysis. The DEM itself was not directly used for the hazard analysis, but provided two very important
derived layers: slope and aspect. The DEM was used, to a certain extent, as an input for the defensible space analysis for the Rattlesnake Valley. This will be discussed further in Section 5.2.

The Missoula County DEM is shown in Figure 5.1.1. The slope and aspect layers were
derived as previously described in section 3.2. For the fire behavior polygon overlay (slope: aspect: fuels), the slope and aspect layers were classified into discrete classes. Slope classes (Figure 5.1.2) were grouped in 10\(^\circ\) increments up to 100\(^\circ\). Any areas with less than 5\(^\circ\) slope were classified as "flat." For the BEHAVE calculations, all slope values above 100\(^\circ\) were placed in a single class. This had little impact, if any, on the hazard analysis for interface areas. Building a house on a slope greater than 100\(^\circ\) would be difficult at best.
and as can be seen below, these areas account for only about 1.1% of the total area.

The aspect layer was classified into the four cardinal directions (north, south, east, and west) for the fire behavior analysis. Any areas having a slope less than 5% were classified as “flat.” Figure 5.1.3 shows the aspect map grouped into 8 aspect classes to highlight terrain features.
IFSL Fuel Models

A more detailed description of the IFSL fuel models represented in the Missoula County map is provided in Appendix K. This information can also be found in Anderson, 1982. Figure 5.1.4 shows the Missoula County IFSL fuel model classification from LANDSAT TM data.

Figure 5.1.5 shows the total area represented by each class in the DEM, slope, aspect,
and IFSL fuel model layers. These were created from summary tables produced by the GIS. Note the relatively small area represented by slope values over 100%. Also of note is the large proportion of total area represented by IFSL fuel model 10 -- characterized by continuous, heavy fuel loadings.

**Weather Conditions**

For the purposes of this analysis, two sets of weather inputs were used for fire behavior modeling. These were the weather conditions recorded at the Missoula Airport on the same dates, and at the approximate times, that the Pattee Canyon and Louisiana-Pacific ("LP") Mill fires started (Table 5.1.2).
**Polygon Overlays for Hazard Analysis**

Each of the raw slope, aspect, and IFSL fuel model layers were processed, classified, and converted to polygon layers as described in Chapter 3. All raster layers were at a uniform resolution of 209 ft x 209 ft (1.003 acres/pixel). To apply the BEHAVE model to the information in the GIS layers, the slope, aspect, and fuel layers were combined into a single composite layer through the polygon overlay process. The parameters for the overlay process were set for zero sliver removal to give the maximum detail possible. The database linked to this new overlay was exported to a DBF (Dbase format) file for processing in FoxPro.

Each combination of fuel model, slope class, and aspect in this database was used as input for the BEHAVE model, using the weather parameters detailed in Table 5.1.2. Input values for slope were based on the upper limit of each slope class. Aspect values were used to calculate the fine fuel moisture content for each fuel model. The calculated fuel moisture for each combination of fuel size class and type, and weather conditions, are shown in Table 5.1.3.

<table>
<thead>
<tr>
<th>Weather Parameter</th>
<th>Pattee Canyon Fire</th>
<th>Louisiana-Pacific Mill Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>July 16, 1977</td>
<td>October 16, 1991</td>
</tr>
<tr>
<td>Initial time of fire</td>
<td>16:23 h</td>
<td>14:00 h (approx).</td>
</tr>
<tr>
<td>Time of weather obs.</td>
<td>17:00 h</td>
<td>14:00 h</td>
</tr>
<tr>
<td>Temperature (dry bulb)</td>
<td>90°F</td>
<td>73°F</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>17%</td>
<td>23%</td>
</tr>
<tr>
<td>Wind Speed (knots)</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>Wind Speed (mi/hr)</td>
<td>15</td>
<td>22</td>
</tr>
</tbody>
</table>

**Table 5.1.3. Fuel moisture inputs to the BEHAVE model for the Missoula County hazard analysis.**

<table>
<thead>
<tr>
<th>Fuel Model Component</th>
<th>Pattee Canyon</th>
<th>LP Mill</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-hr timelag</td>
<td>Ref. charts (Tables 5.1.6, 5.1.7)</td>
<td>Ref. Charts (Tables 5.1.6, 5.1.7)</td>
</tr>
<tr>
<td>10-hr timelag</td>
<td>1-hr. moisture + 1%</td>
<td>1-hr. moisture + 1%</td>
</tr>
<tr>
<td>100-hr timelag</td>
<td>1-hr. moisture + 2%</td>
<td>1-hr. moisture + 2%</td>
</tr>
<tr>
<td>Live woody</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Live herbaceous</td>
<td>120%</td>
<td>120%</td>
</tr>
</tbody>
</table>

### 5.1.3. BEHAVE Model Outputs -- Missoula County Hazard Maps

For several reasons, the primary BEHAVE output chosen to represent the level of hazard
was flame length. Flame length is a good indicator of the actual fire intensity; it correlates well with the "Burn Index" component of the National Fire Danger Rating System (Deeming et al., 1978; Cohen and Deeming, 1982), and is a measure of fire behavior that's visually identifiable by fireline personnel. An example of a rate-of-spread map is also shown, primarily to show a different type of fire hazard analysis from a GIS.

Fire researchers have developed standardized charts that identify what firefighting resources can be deployed relative to fire behavior (Rothermel, 1983; Andrews and Rothermel, 1982). These charts relate fire rate of spread, heat produced by the passing flame front, and the resulting fire intensity. Fire intensity is shown by two scales – as flame length, and as the actual heat produced per second in a one-foot “strip” at the front of the flame (BTU/ft/sec.).

These charts, shown in Figures 5.1.6 and 5.1.7, are commonly used guidelines for short-
term suppression planning. They indicate what suppression resources can be used to fight a fire, based on fire behavior, and indicate where extreme fire behavior may present fire control problems. Fire suppression personnel often affectionately refer to these as the “hauling charts” – at less than 4' flame lengths, you’re hauling people to the fire; at 4-8' flame lengths, you’re hauling equipment; with greater than 8' flame lengths, you’re “hauling your rear end out of there.” These classes provide a visual guide as to what suppression resources might be deployed in a particular location, under specific conditions. A more detailed description of these flame length classes, and the fire management implications for each, is presented in Table 5.1.4. The thematic GIS hazard maps of Missoula County and the
Table 5.1.4  Flame length, fireline intensity, and suppression resources that can be used on a fire. See Figures 5.1.6 and 5.1.7 for cross-reference.

<table>
<thead>
<tr>
<th>Flame Length (feet)</th>
<th>Fireline Intensity (Btu/ft/s)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 4</td>
<td>&lt;100</td>
<td>Fire can generally be attacked at the head or flanks by persons using handtools. Handline should be sufficient to hold the fire.</td>
</tr>
<tr>
<td>4-8</td>
<td>100-500</td>
<td>Fires are too intense for direct attack on the head by persons using handtools. Handline cannot be relied upon to hold the fire. Equipment such as plows, dozers, pumpers, and retardant aircraft can be effective.</td>
</tr>
<tr>
<td>8-11</td>
<td>500-1,000</td>
<td>Fires may present serious control problems -- torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.</td>
</tr>
<tr>
<td>&gt; 11</td>
<td>&gt; 1,000</td>
<td>Crowning, spotting, and major fire runs are probable.</td>
</tr>
</tbody>
</table>

(Adapted from Andrews and Rothermel, 1982).

Rattlesnake Valley, shown in Section 5.1.3, are based on the flame length classes depicted in these “hauling charts.”

**Potential Flame Length Maps**

The final fire behavior maps were themed according to the classes described in Table 5.1.4. The first potential flame length map is shown in Figure 5.1.8; this map was derived from the Pattee Canyon fire weather conditions. The second flame length map, for the LP Mill fire weather conditions, is shown in Figure 5.1.9. These two scenarios show distinct differences in predicted flame length, resulting primarily from very different weather conditions used as input to the BEHAVE model. The Pattee Canyon scenario depicts a situation common to mid-summer, “typical” fire season conditions. The LP Mill fire scenario, on the other hand, is very good example of a late-season passage of a dry cold front.

As can be seen for both scenarios, most of the areas would exhibit a flame length of greater than 8 feet. Fires would probably present serious control problems, and in interface areas,
would be very destructive. This was the case in 1977 with the Pattee Canyon fire, and there was potential for it in the LP Mill fire. However, a comparison of the Pattee Canyon and LP Mill fire weather conditions shows distinct differences in the predicted fire behavior resulting from different weather inputs to the BEHAVE model. These maps show how hazard for a specific area changes dramatically with changes in the weather.
They also point out the advantages of a probabilistic type of hazard modeling. For longer-range fire management planning and suppression resource allocation, a "probabilistic" model would be the most appropriate. This type of model is more labor intensive to set up initially, but provides a better assessment of the potential fire intensity (or rate of spread) in relation to actual historic conditions for a region (Hirsch, 1994).
Rate of Spread Maps

For the Pattee Canyon scenario, a rate-of-spread (ROS) map was also included in the analysis (Figure 5.1.10). By itself, the rate of spread of a wildfire does not necessarily indicate potential fire intensity, so is not as direct a factor in the destructive potential of an interface fire. However, the ROS map will indicate the maximum spread rate of a fire under a given set of conditions. This is important in assessing how fast a fire might spread and how large an area it might burn. As with the flame length maps, the “snapshot” and probabilistic ap-
Elevation and Fuel Moisture Correction

The hazard maps shown in the previous figures are based on a very gross assumption -- that the fire behavior at any given point on the map results from a single combination of weather conditions. What these maps then actually show is a "snapshot" not only of one particular set of weather inputs, but a "continuum of snapshots" across very diverse combinations of fuels and topography. Given the great diversity in regional climate throughout the county, it's highly unlikely that the weather will be the same for all points at all elevations simultaneously. In fact, it's not uncommon for fire danger in the Missoula Valley to be extreme at the same time many areas near Seeley Lake are still covered with snow.

This presents a problem for modeling "actual" hazard conditions for a large area on a given day. One of the constraints of fire behavior modeling is that the weather conditions used are valid only for a limited range of elevations in the vicinity of where the weather data was collected (Figure 5.1.11). The actual weather conditions recorded at a site are considered

![Diagram of Elevation effects on fine fuel moisture adjustments.](image)

**Figure 5.1.11.** Elevation effects on fine fuel moisture adjustments. For predicting fine fuel moisture +/- 1,000' of where the weather is actually measured, no corrections are necessary. For areas +/- 1000' - 2000' from the measurement site, corrections (A or B) must be used. For areas that differ from the measurement site by more than 2,000', new weather readings or forecasts are necessary (from NWCG, 1992).
valid for up to 1,000 feet in elevation above or below the site. For 1,000 - 2,000 feet above or below, one can use corrections for the dead fuel moisture given in the fine fuel moisture reference tables. For sites that differ in elevation by more than 2,000 feet in elevation, new weather measurements must be taken (NWCG, 1992).

For an area as diverse in topography as Missoula County, these corrections must be considered in order to accurately portray potential fire behavior. A GIS has some features that help handle this problem. In the MODELLER module of PAMAP, one raster layer can be modified by inputs from one or more other raster layers. Using the DEM as an input layer, the user can specify that only the areas within 1,000 feet of the weather measurement site be considered for fire behavior modeling using the standard fine fuel moisture corrections. Areas that lie within 1,000 to 2,000 feet from the weather measurement site will require different fuel moisture corrections (above and below the weather measurement site), and areas that lie further than 2,000 feet in elevation from the weather measurement site will not be considered for fire behavior modeling.

This technique is demonstrated here for the Pattee Canyon and LP Mill fires. For both fires, the weather parameters used in fire behavior modeling were measured at the Missoula Airport, located in the middle of the Missoula Valley at an elevation of 3,200 feet. Figure 5.1.12 shows the +/- 1,000 ft. zones from this location. The flame length map for the Pattee Canyon weather conditions was then masked to exclude all areas not within 1,000 ft. elevation of the Missoula Airport (2,200 - 4,200 ft.). Predicted fire behavior is shown only for those areas within +/- 1,000 ft. in elevation of the airport, as the standard ("L") fuel moisture correction values were used for this fire behavior modeling (Figure 5.1.13). The result is a display of predicted fire behavior for only the areas in which the predicted fine fuel moistures are valid.

If one wanted to consider the additional areas up to 2,000 ft. above or below the weather measurement site, MODELLER could be used to mask three separate zones – those areas for which standard fine fuel moisture corrections are needed (+/- 1,000 ft.), those areas where
Figure 5.1.12. Fine fuel moisture correction zones for weather measured at the Missoula Airport (Pattee Canyon and LP Mill Fire hazard maps, Figs. 5.1.8 - 5.1.10). Zones shown indicate areas for which standard fine fuel moisture corrections were made (+/- 1,000 ft.), and those areas where other corrections are needed (+/- 1,000 to 2,000 ft.), and areas for which a given weather site’s data is not valid (>2000 ft. from the measurement site). Note that the minimum elevation in Missoula County is 2,900 ft., so fine fuel moisture corrections would be necessary only for sites above the valley floor.
The inclusion of the additional areas 1,000-2,000 ft. above the weather measurement site does pose some complications. Fine fuel moisture corrections are dependent on both slope and aspect, and the percent vegetative cover. Therefore, including these sites in the display would entail re-calculating the fire behavior outputs for each combination of slope, aspect, fuel
model, and fuel moisture conditions. At this point, an automated procedure would definitely be in order!

For examining the entire county, additional weather information from other monitoring sites would be necessary for improving the reliability of the fire behavior maps. Zones of influence would also need to be delineated for each weather site. One could conceivably construct polygons in the GIS that represent zones of influence for each weather station site -- "thiessen polygons" (see Appendix A). Topographic features could also be incorporated in the process to modify the extent of each site’s influence (EPS, 1991). Much of this process would necessarily need to be automated within the GIS and the external DBMS; the sheer volume of data and computations necessary would be overwhelming to do manually.

**Tabular Summaries of Flame Length Maps**

Tables 5.1.5 provides a summary of the proportion of the total county area represented in each flame length class. This table correspond to the GIS maps shown in Figures 5.1.8 and 5.1.9. These summaries were created using PAMAP’s “Report Surface Values” feature, which generates a report of the values shown on each (surface or polygon) map layer. This feature not only allows the user to summarize complex map information in tabular format, but in

<table>
<thead>
<tr>
<th>Flame Length Class</th>
<th># of Pixels</th>
<th>% of Total Area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LP Mill Fire Weather</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“0”</td>
<td>34,341</td>
<td>2.03</td>
</tr>
<tr>
<td>“0.1”</td>
<td>21,340</td>
<td>1.26</td>
</tr>
<tr>
<td>&lt; 4 ft.</td>
<td>11,642</td>
<td>0.69</td>
</tr>
<tr>
<td>4-8 ft.</td>
<td>16,195</td>
<td>0.96</td>
</tr>
<tr>
<td>8-11 ft.</td>
<td>1,020,803</td>
<td>60.36</td>
</tr>
<tr>
<td>&gt; 11 ft.</td>
<td>586,606</td>
<td>34.69</td>
</tr>
<tr>
<td><strong>Pattee Canyon Fire Weather</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“0”</td>
<td>34,341</td>
<td>2.03</td>
</tr>
<tr>
<td>“0.1”</td>
<td>21,340</td>
<td>1.26</td>
</tr>
<tr>
<td>&lt; 4 ft.</td>
<td>11,642</td>
<td>0.39</td>
</tr>
<tr>
<td>4-8 ft.</td>
<td>27,420</td>
<td>1.62</td>
</tr>
<tr>
<td>8-11 ft.</td>
<td>22,050</td>
<td>1.30</td>
</tr>
<tr>
<td>&gt;11 ft.</td>
<td>1,574,135</td>
<td>93.09</td>
</tr>
</tbody>
</table>
conjunction with the polygon overlay process, it also facilitates the cross-tabulation of the
total area of each flame length class falling within other areas (such as jurisdictional areas).

Note that the “non-fuels” were treated separately from the standard IFSL fuel models. Any
areas classified as rock, bare dirt, or water were assigned a flame length values of zero, and
any area classified as “urban” was assigned a flame length value of 0.1 ft., regardless of other
factors. These areas do not conform to the IFSL fuel model system; they represent areas that
are inherently non-flammable, or nearly so. Dirt, rock, and open water surfaces do not burn
and should necessarily have a zero value. Urban or suburban areas with landscaped yards
might have some flammable material present, but not enough to present a fire hazard over a
large enough contiguous area to be of concern for the scope of this analysis.

5.1.4 Hazard Maps -- The Rattlesnake Valley
The hazard maps for the Rattlesnake Valley were generated in much the same manner as those
for Missoula County – by overlaying the fuels, slope, and aspect maps and determining the
potential flame length based on output from the BEHAVE model. One key difference is that
they were not based on an actual set of weather conditions as with the Missoula County maps.
The primary purposes of the Rattlesnake hazard maps were (1) to test the process of fire
behavior modeling with a GIS for application to a larger area (Missoula County), and (2) for
use in the defensible space analysis. Therefore, this hazard analysis was kept somewhat
simple and “generic” and will be discussed in greater detail later in section 5.2.

5.2 DEFENSIBLE SPACE ANALYSIS
As reviewed in Chapter 2, defensible space involves clearing flammable materials (vegetation
and other) in proximity to structures. The type of wildland fuels present, and the local terrain,
determine the amount of defensible space needed. As will be shown in this section, the
proximity analysis capabilities of a GIS work well for determining where and how much
defensible space is needed, based on local site characteristics.
5.2.1 Buffer Zone Analysis

Buffer zone analysis is a powerful spatial analysis function of a GIS. It allows the user to produce buffer zones of user-defined width around map features or polygons. Weighting factors can be used to modify the width of buffer zones; these can be input as user-defined numbers, or derived from quantitative information in other map layers. Where another raster layer is used for weighting, the actual influence it has on the buffer zone layer can be further modified by multiplying values in that layer by a chosen value, adding a constant factor, or application of a mathematical formula to the modifying layer.

5.2.2 Buffer Zone Analysis and Defensible Space

A polygon layer in the Rattlesnake map shows the location of each of the 1,870 houses in the valley; information in the database describes the relative flammability of each roof (Figure 5.2.1). Using the “Buffers from Features” option in the ANALYZER module of PAMAP, two buffer zones were specified around each house — one 30 feet from the structure, and a second zone 70 feet further out. These correspond to the primary and secondary clearance zones specified by published guidelines (MT DSL, 1993). The DEM layer was used to determine the elevation of each house, and the aspect layer to determine which directions are upslope, downslope, or cross-slope from each house. The discussion later in this chapter will illustrate the importance of directionality in relation to the position of a house on a slope.

Assumptions

There were several general assumptions made in assigning weighting factors for the delineation of buffer zones in the defensible space analysis:

(1) The direction of fire spread was assumed to be uphill in every case. This may not necessarily be true 100% of the time. However, it would be difficult, if not impossible, to account for localized weather conditions around each house. Given the great variability of weather conditions in mountainous terrain, this assumption had to be made for the sake of simplifying the analysis.

(2) Because of (1), the zone downhill from each house is assumed to be more critical, and therefore would need to be more extensive, than the areas uphill from the same house. Wildfires moving uphill (toward a house) burn faster and spread more rapidly than fires backing downhill. Cross-slope zones would fall somewhere in between.
The actual roof type is not of primary importance in the basic analysis of defensible space needs. This assumption was made because of the mechanism by which a flammable roof contributes to the wildfire threat to a house.

A wildfire can present a threat to a house in several ways — by radiated heat, direct flame impingement, and airborne embers (firebrands). The roof is the most vulnerable part of the house for ignition by firebrands, and airborne firebrands are responsible for the majority of houses burned in interface fires (Moore, 1981). Where large trees are present between an advancing fire and a house, most of the firebrands fall in the vicinity of the tree from which they originated — in the absence of strong winds (Foote et al., 1991).

However, the reducing the amount of flammable vegetation immediately adjacent to a structure is far more important for keeping the actual flaming front of a fire away from a structure; this reduces the heat intensity and the possibility of direct flame impingement on the structure. With strong winds, firebrands can often travel a far greater distance than the width of a defensible space zone. Therefore, a combination of defensible space and a fire-resistant roof are needed to maximize the survivability of a structure in a wildfire.

Thus, for this analysis, construction features for all houses are treated the same for determining defensible space needs. Information about the roof flammability is included in the database for reference only. Depending on the specific fuel types represented and the roof flammability information in the database it is theoretically possible to further modify the buffer zones according to roof flammability for each house to account for potential firebrand production and transport from trees. However, this was not done for this study. Modeling firebrand production, and direction and distance of airborne firebrand travel, goes beyond the intent and capabilities of BEHAVE. A more spatially explicit fire behavior modeling system, such as FARSITE, would be necessary for this.

5.2.3 Inputs

Input Map Layers

For this analysis, the “ANALYZER -- PROXIMITY” module of PAMAP was used
(Distance from Feature). A surface cover of house locations was used as the starting point; Figure 5.2.1 shows a schematic diagram of houses (and roads) in the Rattlesnake Valley. The house location map layer (level 25; see Appendix G) was used for the derived surface layer of house locations. The DEM (Figure 5.2.2) and aspect
Figure 5.2.2. Rattlesnake Valley Digital Elevation Model (DEM).

Figure 5.2.3. Rattlesnake fuel model classifications. IFSL and non-IFSL fuel models are included (see Appendix K for descriptions).

(Figure 5.2.5) layers provided information about the direction of slope in relation each house’s position. The slope layer (Figure 5.2.4) was used for both the flame length map and as a weighting factor in the defensible space analysis. Input layers used for the analysis are summarized in Table 5.2.1.

The slope and IFSL fuel model (Figure 5.2.3) layers are the two most important variables in defining the width of the defensible space zones. These are key GIS inputs to the BEHAVE model, in addition to weather parameters (Andrews, 1983). The slope layer was used directly as a weighting factor. Increasing slope contributes
Table 5.2.1. GIS input layers for the defensible space analysis (RATTLE2)

<table>
<thead>
<tr>
<th>GIS Layer</th>
<th>Type</th>
<th>Figure</th>
<th>Use</th>
<th>Special Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houses</td>
<td>Classified surface</td>
<td>5.2.1</td>
<td>Starting point for proximity analysis</td>
<td></td>
</tr>
<tr>
<td>DEM</td>
<td>&quot;Raw&quot; surface</td>
<td>5.2.2</td>
<td>Position of house on slope; slope direction</td>
<td></td>
</tr>
<tr>
<td>Aspect</td>
<td>&quot;Raw&quot; surface</td>
<td>5.2.5</td>
<td>Slope direction</td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td>&quot;Raw&quot; surface</td>
<td>5.2.4</td>
<td>Weighting in corridor analysis</td>
<td>Must use inverse weighting</td>
</tr>
<tr>
<td>IFSL Fuel Model</td>
<td>Classified surface</td>
<td>5.2.3</td>
<td>Derivation of Flame length layer</td>
<td></td>
</tr>
<tr>
<td>Flame length</td>
<td>Classified surface</td>
<td>5.2.7</td>
<td>Weighting in corridor analysis</td>
<td>Must use inverse weighting</td>
</tr>
</tbody>
</table>
directly to a greater fire intensity and rate of spread. In fact, fire rate of spread is
double at 30% slope compared to level ground (Dennis, 1983). Therefore, the width
of a defensible space zone must increase with an increase in slope -- particularly
downslope from a structure.

The fuels around a structure also influence the fire intensity, and the defensible space
zones need to reflect this. There is no quantifiable parameter of the IFSL fuel models
that can be readily used as a weighting factor. However, since the fuel model drives
the fire intensity output of BEHAVE to a great degree, a flame length layer was used
as a second weighting factor instead. This is discussed in greater detail later in this
section. Thus, the combination of flame length (as a function of fuel model) and
magnitude of slope serve as reasonable weighting factors to modify the defensible
space "buffer" zone.

There was one minor problem with using the slope and flame length layers as a
weighting factors. In PAMAP, the width of a buffer zone increases with increasing
weighting values. This would decrease the width of a defensible space zone with
increasing slope or flame length values -- exactly the opposite of what should occur.
This problem was relatively simple to overcome. The PROXIMITY functions of
PAMAP's ANALYZER module allow the user to process an input (weighting) surface
layer by using a multiplier and a constant such that it acts as an inverse weighting.

Another problem encountered in using the raw slope and flame length values as
weights was the presence of zeros values in these layers. Weighting factors must be
greater than zero or no buffer zones will be produced. This was overcome by the
same process as the inverse weighting issue; the slope and flame length layers were
modified as inverse weighting factors, to nonzero values, by a single formula:

\[ \text{Weight} = (\text{Slope}^{(-0.01)}) + 1 \]
\[ \text{Weight} = (\text{FL\_LGTH}^{(-0.01)}) + 1 \]
Table 5.2.2. Transformation of slope values by formula in proximity analysis.

<table>
<thead>
<tr>
<th>Actual Slope (Max. Value, percent)</th>
<th>Modified Weighting (X*-0.01)+1</th>
<th>Resulting modification of 100 foot width</th>
<th>MT DSL Guidelines (ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>100 (no change)</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>0.9</td>
<td>111</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>0.8</td>
<td>125</td>
<td>120</td>
</tr>
<tr>
<td>30</td>
<td>0.7</td>
<td>143</td>
<td>150</td>
</tr>
<tr>
<td>40</td>
<td>0.6</td>
<td>167</td>
<td>—</td>
</tr>
<tr>
<td>50</td>
<td>0.5</td>
<td>200</td>
<td>—</td>
</tr>
<tr>
<td>60</td>
<td>0.4</td>
<td>250</td>
<td>—</td>
</tr>
</tbody>
</table>

Table 5.2.2 shows the weighting factors that resulted from this, and a comparison of the outcome with the recommendations of the MT DSL guidelines.

Slope values 100% or more would result in weighting factors equal to or less than zero by the formula used. Additionally, the BEHAVE model only accepts slope input values up to 100%. Therefore, all slope values 100% or more were transformed to a value of 99% in the MODELER module of PAMAP (Surface Modeling). This had minimal impact on the analysis -- less than 0.6% of the surface had slope values greater than 99%, and residential development does not exist on such steep slopes.

*Direction Weighting and Magnitude*

The inverse-slope layer, modified by formula, provided a continuum of input values for the magnitude of the influence of slope on the width of the buffer zone. In the final analysis, the buffer zones were then further modified in a "secondary" weighting according to the direction of slope in relation to the house -- "differential position" weighting. Smaller values (uphill direction from a house) resulted in narrower buffer widths than larger values (downhill from the house).

How much differential positional weighting is enough? It depends on the source and intent of the published defensible space recommendations. Most agree that a 30-foot, nonflammable clearance zone is needed in immediate proximity to a house. The secondary clearance/thinning zones are in less agreement from one publication to
Table 5.2.3. Comparison of defensible space recommendations from two different sources.

<table>
<thead>
<tr>
<th>Source</th>
<th>Slope (%)</th>
<th>Distance from Structure, feet (defensible space)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Up slope (ft.)</td>
</tr>
<tr>
<td>Moore, 1981</td>
<td>0-20</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>21-40</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>41-60</td>
<td>200</td>
</tr>
<tr>
<td>MT DSL, 1993</td>
<td>0-10</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>100</td>
</tr>
</tbody>
</table>

another. For instance, the recommendations shown in Table 5.2.3, from two separate sources, use different slope classes and give different distances for the up-, side-, and downslope clearance distances. Also, no adjustment factors were given in either set of guidelines for type and height of vegetation.

Why the difference? This is not clear from the literature, but there are some possible explanations. First, "defensible space" is still as much "art" as science. For instance, defensible space in a California chaparral fuel type will necessarily be different than in a lodgepole pine fuel type of western Montana. There are very fundamental differences in surface fire -- and crown fire -- behavior between these two fuel types.

Determining the amount of defensible space needed for one fuel type versus the other will involve some judgement based on experience and local conditions. Some recent research promises to provide a mathematical model for predicting the probability of structure ignition/loss based to a large degree on defensible space (Cohen et al., 1991; Cohen et al., 1993). This would remove much of the subjectivity from defensible space determination.

Defensible space recommendations will also tend to reflect an agency's mandate or directives. The recommended clearance distances might vary depending on the intended "use" of the defensible space -- whether it is to improve structure survivability in the absence of suppression resources, or to serve as a place for firefighters...
to "make a stand." A wildland agency may be less concerned about survivability of a structure than the structure's contribution to a wildfire's spread, whereas a structural fire agency may be primarily concerned about protecting the structure itself and less so about the surrounding wildlands.

Figure 5.2.6 shows a diagrammatic representation of the slope positional weightings used to generate the defensible space buffer zones for the Rattlesnake map. There was no "magical" formula used to determine these. Rather, a process of trial and error was used to develop a combination of weightings that would give comparable buffer zone widths to those indicated in the MT DSL guidelines. The key factor in assigning these direction weightings was that without doing so, the GIS would assign the same slope and flame length weightings uphill as downhill.

However, the zone downhill from a house is the most important, and necessarily needed to have a greater weighting. Cross-slope areas were given a slightly higher weighting than uphill to account for some cross-slope spread of a fire under variable local wind conditions. Local surface winds tend to travel up drainages during the day after commencement of "upslope winds" (NWCG, 1981), and could spread a fire

![Diagram showing slope positional weightings](image)

**Figure 5.2.6.** Secondary weightings for defensible space "buffer" zones, based on the position of a pixel in relation to a house's position on a slope.
in a cross-slope direction. However, under all but the most extreme conditions, the slope’s influence on fire behavior is far greater than that of the wind, and the downhill side of a house is the most vulnerable.

**Fuel Models as Weighting Factors**

The type of vegetation (fuel model) present in the vicinity of a structure directly influences the intensity of a wildfire, and hence, the defensible space needed. IFSL fuel models are based on the loading (tons/acre) of dead surface fuels in the various timelag classes and do not include a “flammability” factor per se. Rather, the predicted fire intensity for a given fuel model is determined by the interaction of fuels, weather, and topography. Thus, for this analysis, the flame length value from a hazard map layer was used rather than the fuel model. This does result in some redundancy of slope’s influence in this analysis, since slope is included in the calculation of flame length and is also directly used as a separate weighting factor. However, fire intensity is a far less subjective weighting factor than would be a numerical value arbitrarily assigned to a fuel model for weighting purposes.

**Derivation of Flame Length Maps**

The flame length maps for the Rattlesnake Valley were derived by the same method as with the MSLACO map. An overlay of IFSL fuel models, slope, and aspect were used for inputs into the BEHAVE model (Figures 5.2.3 - 5.2.5). The actual BEHAVE runs were completed with data from an external database. In this case, “hypothetical” rather than actual weather conditions were used. For these hazard maps, the following weather inputs were used for the BEHAVE model: 85EF, 20% relative humidity, and either no wind (Figure 5.2.7) or a 10 m.p.h. upslope wind (Figure 5.2.8). The direction of maximum fire spread was assumed to be upslope in all cases.

The notable difference between the two fire behavior maps, resulting from a change in a single weather parameter, again illustrates the point that probabilistic hazard
modeling, based on actual historic weather conditions, would be of great use in determining longer-term fire management planning and hazard mitigation strategies.

The reason hypothetical weather conditions were used in this analysis is that "average worst case" conditions are more appropriate than infrequent, extreme weather conditions for the purpose of hazard mitigation. This principle is illustrated by the analogy of flood plains; most planning concerns 100-year flood cycles, rather than the infrequent (but theoretically possible) 500- or 1,000-year floods.
The same principle holds true for defensible space. Defensible space itself is in no way a guarantee that a house will survive a wildfire. It merely increases the odds in favor of the house's survival, and gives firefighters a zone in which to work more safely. Planning for the absolute worst case possible would probably not be socially or aesthetically acceptable in terms of the degree of vegetation modification or removal that would be required. Rather, it’s more reasonable to use conditions more typical of an “average worst day” in the peak of the fire season.

Flame Length as a Weighting Factor

The flame length map derived using a 10 m.p.h. wind (Figure 5.2.8) was used as the flame length weighting factor in the defensible space analysis. As with slope, the way that PAMAP uses weighting inputs would have resulted in narrower buffer zones produced from higher flame length values. Therefore, the inverse value of the predicted flame length was used in the analysis as previously described.

5.2.4 Outputs -- Defensible Space Maps

The GIS used all the input parameters described above to generate a surface cover of “modified buffer zones.” That is, the final cover contains values that are analogous to the 30- and 100-foot zones on flat ground. For instance, a pixel on a simple, linear corridor map that had a “distance-from” value of 100 ft, modified by a total combined weighting of 0.5, would have a value of 50.0 on the modified buffer layer. Thus, the “100 foot equivalent” on a steep slope with heavy fuels would occur much further out from the structure.

Figure 5.2.9 shows a linear “distance-from” map for the houses in the Rattlesnake Valley; (unmodified) 30- and 100-foot buffers for the Rattlesnake are highlighted. Figure 5.2.10 shows the same type of buffer zones, but modified by slope and flame length weightings. As slope or flame length values increase, the “30” and “100” numerical values in the modified buffer map occur further out from the structure.
Figures 5.2.11 and 5.2.12 show the results of the defensible space analysis in more detail for the upper Rattlesnake. In these two figures, one can see the areas contributing to a greater need for defensible space -- steep slopes and heavy fuels. Note that for structures located in flat areas, surrounded by irrigated fields and green lawns, the defensible space needs, and zones delineated by the GIS analysis, are minimal.
In Figure 5.2.13, a photo of a portion of the upper Rattlesnake area is compared with a perspective view of this area (Figure 5.2.14) that shows hazard classes (per Andrews, 1986). Figure 5.2.14 corresponds to the hazard map in Figure 5.2.8. Figure 5.2.15 shows the same perspective view, highlighting the defensible space zones.
Figure 5.2.13. Aerial oblique view of the upper Rattlesnake, looking to the southeast.

Figure 5.2.14. A perspective view of the same area, showing the GIS-derived hazard classes from Figure 5.2.8 (per Andrews, 1986). Without adequate defensible space, most of the houses on the slopes would be considered "write-offs" in the event of a large wildfire.

Figure 5.2.15. Perspective view of defensible space zones, upper Rattlesnake.
In Figure 5.2.16, the defensible space zones have been overlaid onto the original IFSL fuel model map and fire behavior recalculated. In this case, the 30-foot fuel removal zone was assigned to IFSL model 8 (moderate surface fire behavior) and the 100-foot secondary thinning zone was designated as IFSL fuel model 9.

![Figure 5.2.16. Predicted fire behavior with defensible space. The defensible space zones in Figure 5.2.15 were overlaid onto the IFSL fuel model map and fire behavior re-calculated. In this case, the 30-foot “immediate proximity” zone was designated as IFSL model 8 (moderate surface fire behavior) and the 100-foot secondary zone was designated as IFSL fuel model 9. Two shades of green are used to designate the "0-4 ft." flame length class merely to delineate the two defensible space zones.](image)

The key result of the defensible space analysis is a modified proximity map showing specifically where and how much defensible space is needed in relation to each house, accounting for the roof type and surrounding conditions. From this type of analysis, fire managers would know ahead of time which houses have adequate defensible space and can be protected in the event of a wildfire, allowing them to better allocate scarce fire suppression resources.

This analysis, in conjunction with the comparative fire behavior maps, also provides a graphic, persuasive tool to educate homeowners of the need to reduce the hazards
around their homes, and demonstrate to local officials the value of greenbelts and other preventative measures to the community. It can also be a warning as to which areas would be too dangerous for people to remain in the event of a wildfire — areas that would be high priority for evacuation of residents, and questionable places to send firefighters and equipment.

5.3 SPATIAL RISK

"The cause of lightning," Alice said very decidedly, for she felt quite sure about this, "is the thunder -- no, no!" she hastily corrected herself, "I meant it the other way."

"It's too late to correct it," said the Red Queen. "When you've once said a thing, that fixes it, and you must take the consequences."

-- Lewis Carroll; Alice Through the Looking Glass

Risk is generally defined as any ignition source that can start a fire. It differs distinctly from hazard, which is the intensity and rate of spread of a fire once an ignition occurs. In this thesis, risk specifically denotes the probability that a fire will start in a given location, and is further classified as either lightning- or human-caused. Risk is an important component of the fire problem in Missoula County; theignitions each year number in the hundreds, and human-caused ignitions are tightly clustered around population centers and road corridors. Therefore, the spatial distribution of risk in relation to geographic and demographic features -- spatial risk -- warrants a closer examination.

5.3.1 Spatial Risk Variables

The dependent variable was human-caused fire occurrence, and the primary independent variables examined were population density and proximity to roads. Most of the human-caused fires appeared to be closely associated with primary roads and population centers, presenting an ideal opportunity for investigating the concept of spatial risk analysis.
Fire Occurrence

For this part of the project, Jon Skinner and I collected fire occurrence records from every fire protection agency in Missoula County, fire service organizations (FSOs) and wildland agencies alike. The ten-year period from 1981 to 1990 was examined. This encompassed a sufficient time span to obtain a large set of data, yet was short enough that the impact of temporal changes in demographics and protection boundaries was minimized. It was also the ten-year period whose end coincided with the 1990 U.S. Census, thereby providing current population data for use in the analysis.

From 1981 to 1990, there were 2,542 fires reported as wildfires in Missoula County. Responsibility for each fire was assigned to a single jurisdictional agency. In cases of overlapping jurisdictions, the responsibility of the fire was assigned to the first arriving personnel; this was usually the FSO. Some FSOs did not keep records of wildfires to which a wildland agency also responded. In this case, the responsibility of the fire was assigned to the wildland agency. No records were available from the Greenough-Potomac Fire Service Area, which was not formed until after 1990. However, the MT DSL and several FSOs in that part of the county had records of fires occurring within Greenough-Potomac’s current jurisdictional area, providing a fairly reliable fire occurrence history for 1981 to 1990.

The spatial distribution of human- and lightning-caused wildfires is shown in Figures 5.3.1 and 5.3.2, respectively. 65.9% of all wildland fires occurring in Missoula County between 1981 and 1990 were human-caused. The geographic locations of fires reported by wildland agencies are based on quarter-quarter sections, each representing approximately 40 acres. Because these fires constituted the majority of the wildfires, and because the street address location method used by FSOs did not tie fire occurrence to a specific unit of land area per se, the quarter-quarter section location method was used for mapping all fires. This provided a common unit of land
area across all agencies for quantifying fire occurrence.

The number of fires falling within each quarter-quarter section were totalled using a small program within FoxPro, the external database manager, and ranged from zero to eight. Within the database, the total number of fires, as well as the total number of only the human- or lightning-caused fires, were summed for each quarter-quarter.

Figure 5.3.1. Human-caused fires, 1981-1990 (Missoula County). Each red dot represents one fire, plotted by point of origin. The IFSL fuel map and major highways are shown for reference. There were 1,678 human-caused fires reported during this time period.
Human-caused fire risk is the most predominant in the county, and these fires can be associated readily with specific human-related attributes of an area. The spatial risk analysis presented in this thesis focuses on human-caused wildfires, although lightning-caused fire data is included for comparison. The quarter-quarter section map of
human-caused wildfires is shown in Figure 5.3.3.

**Population Density**

Population density is important since where there are people, there are likely to be fires caused by people. The 1990 population density map for Missoula County is
shown in Figure 5.3.4. Two general trends were noted in the MSLACO dataset. First, there were more human-caused fires where the population density was higher. Also, there were some areas of tightly clustered human-caused fire occurrences in proximity to primary roads and highways, even where population density was low.
Road Proximity

In Figure 5.3.5, quarter-mile corridors in proximity to primary roads are shown for the Missoula Valley and vicinity. An overlay of the human-caused wildfires was added to illustrate the clustering of fires near the major roads -- particularly highways and primary access roads in population centers.

Figure 5.3.5. Proximity to highways, paved streets, and primary dirt/gravel roads, Missoula Valley and vicinity. Corridors shown are in 1/4 mile increments. Human-caused fire occurrences from 1981 - 1990 are also shown.
Other Independent Variables

Other independent variables -- land ownership and fire protection jurisdictions in particular -- also could be factors in the spatial distribution of human-caused fires as well. Land ownership serves as an indicator of predominant land use, and is closely related to population density since residential development occurs largely on private, non-commercial land. Fire protection jurisdictions (particularly FSOs vs. wildland agencies) highlight divergent wildland fire management directives, and are also closely related to population density; FSOs protect largely private, non-industrial land and wildland agencies protect primarily the less populated state and federal lands, as well as industrial timberlands.

However, these variables were not included in the spatial risk analysis for the sake of simplicity in deriving the regression equations. The two independent variables chosen (population density and road proximity) accounted for the vast majority of human-caused fire occurrence, as will be discussed later in this section.

5.3.2 Method of Spatial Risk Analysis

The spatial risk analysis described here uses a GIS to (1) characterize wildfire occurrence, (2) conduct a Chi-square test to determine if there are any dependencies between the number of human-caused wildfires and population density and road proximity, and (3) develop a predictive model for human-caused wildfire occurrence through regression analysis. The final model provides an estimate of expected fire occurrence based on quantifiable, spatially explicit characteristics of an area. It was derived by applying a statistical analysis program, SYSTAT (SYSTAT, Inc., 1992) to GIS-derived data, using a non-linear regression model. The discussion here deals with theoretical aspects of this analysis, the actual regression analysis, and directions for future work.

5.3.3 Analysis of Risk

Chi-square analysis

One means of exploring the relationship between dependent and independent variables is
the Chi-square ($\chi^2$) test. It allows one to test for a cause-and-effect relationship between an independent and a dependent variable by comparing observed and expected frequencies of event occurrences (Wonnacott and Wonnacott, 1985). The "null hypothesis," $H_0$, stipulates there is no relationship between the dependent and independent variables being compared. A good example is presented by Vega-Garcia et al. (1993).

In assessing the relationship between population density and human-caused fire occurrence, the null hypothesis would be that there is no significant relationship between the two, and the spatial distribution of human-caused wildfires is random in regard to population density. The $\chi^2$ test would then either verify or refute $H_0$.

Road proximity and population density were each grouped into discrete classes. The number of wildfires, human and lightning, were then counted within each class. The $\chi^2$ test compares the expected fire occurrence with the observed fire occurrence for each class, and determines whether $H_0$ is to be rejected or not to be rejected at a certain level of significance. The observed $\chi^2$ value is calculated by the following formula:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

where $E_i = \text{expected frequency in class } i$

$$O_i = \text{observed frequency in class } i$$

Small calculated $\chi^2$ values support $H_0$, while large calculated $\chi^2$ values favor rejection of the null hypothesis $H_0$ of random distribution of fire occurrences. The "standard" critical level for rejecting $H_0$ is $p=0.05$; that is, there is only a 5% chance of not rejecting the null hypothesis (Wonnacott and Wonnacott, 1985). For example, if a particular road distance class is 25.4% of the total county area, the expected number of human-caused fire occurrences in that class is 25.4% of all human-caused fires, or 426 fires, if $H_0$ is true.
Table 5.3.1 outlines the $\chi^2$ test for human-caused fire occurrence and road proximity. Classes indicated are quarter-mile distance corridors from roads, and the area for each is the total area represented by that class; i.e., the 0 - 0.25 mi. class denotes all land area that falls between 0 - 0.25 mi. of a primary road. The null hypothesis is:

$$H_0: \text{The distribution of human-caused fire occurrence is unrelated to road proximity (random).}$$

The degrees of freedom = 12 ($n - 1$ classes) and the calculated $\chi^2 = 2,941$. $H_0$ is rejected when this value exceeds the critical $\chi^2_p$ value for a probability level (p). In this case, $\chi^2_{0.01} = 32.9$. Since $2,941 >> \chi^2_{0.01}$, it is highly unlikely that human-caused fire occurrence is random with regard to road proximity, and $H_0$ is rejected.

<table>
<thead>
<tr>
<th>Distance from Primary Roads</th>
<th>Corridor Area (ac.)</th>
<th>Percent of Total Area</th>
<th>No. of Fires</th>
<th>Expected*</th>
<th>(O-E)^2/E</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 - 0.25</td>
<td>425,631</td>
<td>0.254</td>
<td>1,390</td>
<td>426</td>
<td>2,181</td>
</tr>
<tr>
<td>0.25 - 0.50</td>
<td>263,384</td>
<td>0.157</td>
<td>115</td>
<td>264</td>
<td>84</td>
</tr>
<tr>
<td>0.50 - 0.75</td>
<td>195,913</td>
<td>0.117</td>
<td>50</td>
<td>196</td>
<td>109</td>
</tr>
<tr>
<td>0.75 - 1.00</td>
<td>156,623</td>
<td>0.093</td>
<td>38</td>
<td>157</td>
<td>90</td>
</tr>
<tr>
<td>1.00 - 1.25</td>
<td>115,261</td>
<td>0.068</td>
<td>29</td>
<td>115</td>
<td>64</td>
</tr>
<tr>
<td>1.25 - 1.50</td>
<td>84,019</td>
<td>0.050</td>
<td>13</td>
<td>84</td>
<td>60</td>
</tr>
<tr>
<td>1.50 - 1.75</td>
<td>70,711</td>
<td>0.042</td>
<td>11</td>
<td>71</td>
<td>51</td>
</tr>
<tr>
<td>1.75 - 2.00</td>
<td>54,969</td>
<td>0.033</td>
<td>7</td>
<td>55</td>
<td>42</td>
</tr>
<tr>
<td>2.00 - 2.25</td>
<td>45,404</td>
<td>0.027</td>
<td>7</td>
<td>45</td>
<td>32</td>
</tr>
<tr>
<td>2.25 - 2.50</td>
<td>39,309</td>
<td>0.023</td>
<td>3</td>
<td>39</td>
<td>33</td>
</tr>
<tr>
<td>2.50 - 2.75</td>
<td>32,976</td>
<td>0.020</td>
<td>2</td>
<td>33</td>
<td>29</td>
</tr>
<tr>
<td>2.75 - 3.00</td>
<td>29,188</td>
<td>0.017</td>
<td>6</td>
<td>29</td>
<td>18</td>
</tr>
<tr>
<td>&gt;3.00</td>
<td>163,962</td>
<td>0.098</td>
<td>8</td>
<td>164</td>
<td>148</td>
</tr>
<tr>
<td>Total</td>
<td>1,677,350</td>
<td>1.000</td>
<td>1678</td>
<td>1678</td>
<td>$\chi^2=2,941$</td>
</tr>
</tbody>
</table>

* Expected number of fires = (Corridor area/Total area) * (Total no. fires)

The $\chi^2$ test was run in the same manner for road proximity vs. lightning-caused fires, and population density vs. human- and lightning-caused fires. The results are summarized in Table 5.3.2. The "generic" null hypothesis for these tests is that wildfire...
occurrence is random in regard to population density or road proximity.

In the case of road proximity vs lightning-caused fires, the calculated $\chi^2$ value (67.9) is much less than the $\chi^2$ obtained for human-caused fires. However, it is still greater than $\chi^2_{0.001, df=12}$ and the null hypothesis is rejected at the $p=0.001$ level. This is contrary to what one might intuitively expect, as lightning is often perceived as a random occurrence. However, several factors may have led to this result. Reporting of lightning-caused fires is probably more consistent closer to roads; some ignitions resulting in very small fires may not be detected or even reported in remote areas. Additionally, many of the more remote areas of the county (i.e., high-altitude wilderness areas) lack sufficient vegetation to support ignition from lightning.

In the second case examined, fire occurrence vs. population density, the null hypothesis is similar to that for road proximity:

$H_0$: There is no difference in wildfire occurrence (human- or lightning-caused) relative to population density.

For human-caused fires, the calculated $\chi^2$ is much larger than $\chi^2_{0.001}$ and the null hypothesis is soundly rejected. In the case of lightning-caused fires, the $\chi^2$ value of 11.4 is less than the critical $\chi^2$ value at even the $p=0.1$ level. Thus, though lightning-
Regression Analysis -- Road Proximity

The GIS data was subjected to further statistical analysis to derive a predictive model for human-caused fire occurrence based on road proximity and population density. Each independent variable was assessed separately in relation to human-caused fire occurrence; the final regression analysis incorporated both independent variables.

Table 5.3.3 summarizes the data used in the regression analyses for human-caused fire occurrence in relation to road proximity. Upon plotting the no. of fires/100,000 acres against road proximity class, it became apparent that the relationship was logarithmic rather than linear for human-caused fires (Figure 5.3.6). The non-linear-
Figure 5.3.6. *Human- and lightning-caused fire occurrence by road proximity classes (0.25 mi. increments). Values for the upper end of each distance class are indicated on the x-axis. Fire occurrence data is from 1981 - 1990. Also shown is human-caused fire occurrence as predicted by the derived regression equation (see text on following pages).*

The statistical model used in SYSTAT was:

\[ \text{LOGCNT2} = \text{CONSTANT} + \text{DISTANCE} + (\text{DISTANCE} \times \text{DISTANCE}) \]

A summary table of the regression analysis and Analysis of Variance output from SYSTAT for this model are shown below. Note that the F-Ratio (explained variance/unexplained variance) is larger than the critical F-ratio value at \( p=0.001 \) (16.4), thus providing further reason to reject \( H_0 \).
DEP VAR: LOGCNT2
N: 12
MULTIPLE R: 0.889
SQUARED MULTIPLE R: 0.790
ADJUSTED SQUARED MULTIPLE R: 0.744
STANDARD ERROR OF ESTIMATE: 0.511

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>COEFFICIENT</th>
<th>STD ERROR</th>
<th>STD COEF</th>
<th>TOLERANCE</th>
<th>T</th>
<th>P (2 TAIL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT</td>
<td>5.736</td>
<td>0.528</td>
<td>0.000</td>
<td></td>
<td>10.856</td>
<td>0.000</td>
</tr>
<tr>
<td>DISTANCE</td>
<td>-3.050</td>
<td>0.748</td>
<td>-2.723</td>
<td>0.052</td>
<td>-4.080</td>
<td>0.003</td>
</tr>
<tr>
<td>DISTANCE^2</td>
<td>0.677</td>
<td>0.224</td>
<td>2.016</td>
<td>0.052</td>
<td>3.022</td>
<td>0.014</td>
</tr>
</tbody>
</table>

ANALYSIS OF VARIANCE

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>SUM-OF-SQUARES</th>
<th>DF</th>
<th>MEAN-SQUARE</th>
<th>F-RATIO</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>REGRESSION</td>
<td>8.864</td>
<td>2</td>
<td>4.432</td>
<td>16.956</td>
<td>0.001</td>
</tr>
<tr>
<td>RESIDUAL</td>
<td>2.352</td>
<td>9</td>
<td>0.261</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The regression equation derived from SYSTAT is:

\[ \ln(\text{FIRECNT2}) = 5.736 - 3.050(\text{DISTANCE}) + 0.677(\text{DISTANCE})^2 \]

which transforms to the final equation of

\[ \text{FIRECNT2} = 309.83(e^{-3.05(\text{DISTANCE}) + 0.667(\text{DISTANCE})^2}) \]

This equation was applied to the DISTANCE values in Table 5.3.3, and the resulting values plotted on Figure 5.3.6 for comparison of the predicted fire occurrence to the actual observed fire occurrence for that distance class. This regression provided a reasonable fit to the data, although over-predicted human-caused fire occurrence in the lower road proximity range (0.25 - 1.50 mi.) relative to the observed values.

Regression Analysis -- Population Density

Table 5.3.4 summarizes the data used as input for regression analysis of human-caused fire occurrence in relation to population density. As with road proximity, this relationship appeared to be logarithmic. Therefore, population density values were transformed to
Table 5.3.4. Summary of human-caused fire occurrence data by population density. Names of variables used in the SYSTAT regression analysis are indicated in uppercase, and are shaded grey.

<table>
<thead>
<tr>
<th>Population Dens. (No./mi²)</th>
<th>Maximum for Class</th>
<th>Class Area (% of total)¹</th>
<th>No. of Human-Caused Fires</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POPDENS</td>
<td></td>
<td>NFIRE_AC</td>
</tr>
<tr>
<td></td>
<td>Maximum (NoVmi^)</td>
<td>Class Area (No. per class)</td>
<td>No./1,000 Ac.</td>
</tr>
<tr>
<td>0-5</td>
<td>5</td>
<td>80.4</td>
<td>476</td>
</tr>
<tr>
<td>5-10</td>
<td>10</td>
<td>5.8</td>
<td>153</td>
</tr>
<tr>
<td>10-50</td>
<td>50</td>
<td>10.8</td>
<td>382</td>
</tr>
<tr>
<td>50-100</td>
<td>100</td>
<td>1.0</td>
<td>86</td>
</tr>
<tr>
<td>100-500</td>
<td>500</td>
<td>1.3</td>
<td>206</td>
</tr>
<tr>
<td>500-1,000</td>
<td>1,000</td>
<td>0.2</td>
<td>77</td>
</tr>
<tr>
<td>1,000-5,000</td>
<td>5,000</td>
<td>0.4</td>
<td>209</td>
</tr>
<tr>
<td>5,000-15,000</td>
<td>15,000</td>
<td>0.1</td>
<td>88</td>
</tr>
</tbody>
</table>

¹ Proportion of total represented by each population density class.
² "LOGDENS" denotes ln(POPDENS), where "ln" is the natural logarithm.
³ The maximum population density in Missoula County is 38,000/mi²; areas with population density above 15,000 total only 186 acres. Due to the small size relative to the total and absence of fires, this class was combined with the 5,000-15,000 class. See text for further discussion.

their natural log, ln. Note that the number of fires per unit area are no/1,000 acres rather than no/100,000 acres as used for the road proximity regression analysis. The unit of land area was of arbitrary; of greater importance was transforming fire occurrence to some common unit of land area of a magnitude such that the numbers were not overly cumbersome for the regression analysis.

The variables NFIRE_AC and LOGDENS from Table 5.3.4 were then put through a similar regression analysis as for (road proximity)*(fire occurrence). The non-linear solution process used by SYSTAT was iterative, modifying parameters at each subsequent iteration to minimize the residual sum-of-squares. The model used was of the form:

\[ NFIRE\_AC = B_0 \cdot (1-\exp(-B_1 \cdot POPDENS/100)) \]

there NFIRE_AC is the number of human-caused wildfires per 1,000 acres, and POPDENS is the population per square mile. The final output from SYSTAT is summarized below.
DEPENDENT VARIABLE IS NFIRE_AC

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>SUM-OF-SQUARES</th>
<th>DF</th>
<th>MEAN-SQUARE</th>
</tr>
</thead>
<tbody>
<tr>
<td>REGRESSION</td>
<td>2942.16286</td>
<td>2</td>
<td>1471.08143</td>
</tr>
<tr>
<td>RESIDUAL</td>
<td>27.60106</td>
<td>6</td>
<td>4.60018</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2969.76400</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>CORRECTED</td>
<td>1457.26400</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

RAW R-SQUARED (1-RESIDUAL/TOTAL) = 0.99071
CORRECTED R-SQUARED (1-RESIDUAL/CORRECTED) = 0.98106

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>ESTIMATE</th>
<th>A.S.E.</th>
<th>LOWER &lt;95%&gt;</th>
<th>UPPER</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0</td>
<td>34.18200</td>
<td>1.56742</td>
<td>30.34666</td>
<td>38.01734</td>
</tr>
<tr>
<td>B1</td>
<td>0.09571</td>
<td>0.01439</td>
<td>0.06051</td>
<td>0.13091</td>
</tr>
</tbody>
</table>

The final equation is:

\[ NFIRE\_AC = 34.182(1 - e^{-0.0009571 \times POPDENS}) \]

This equation was applied to the range of population density values used in deriving the regression equation, and the results shown in Figure 5.3.7.

![Figure 5.3.7](image1.png)

Figure 5.3.7. Human- and Lightning-caused fire occurrence by population density classes. Also shown is human-caused fire occurrence as predicted by the derived regression equation.
As with the road proximity regression, this model tends to overpredict the human-caused fire occurrence in the middle range of the population density, and slightly under-predicts it at the very upper end. However, overall it provides a reasonable estimate of human-caused fire occurrence in relation to population density.

**Multiple Regression Analysis With Two Independent Variables**

The final step in the regression analysis was to derive a model for human-caused fire occurrence based on two independent variables -- population density and road proximity. For this, the input data needed to be represented on a common areal basis. The road corridor polygon raster layer in the GIS was used as the baseline for the independent variable classes. The population density polygon layer was then overlaid onto this. From the resulting overlay, the total population and population density were determined for the area covered by each road corridor class.

The input variables for the SYSTAT routine are summarized in Table 5.3.5. The non-linearity inherent in the data was again removed by taking the natural logarithm of the variables FIRECNT2 and DENSITY. The statistical model used in SYSTAT was

<table>
<thead>
<tr>
<th>Class (Distance from Roads)</th>
<th>DISTANCE (Max. Value)</th>
<th>FIRECNT2 No./100,000 Acres</th>
<th>LOGCNT2 ln(FIRECNT2)</th>
<th>DENSITY Pop./mi.² for class</th>
<th>LOGDENS ln(Density)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 - 0.25</td>
<td>0.25</td>
<td>325.00</td>
<td>5.784</td>
<td>114.62</td>
<td>4.742</td>
</tr>
<tr>
<td>0.25 - 0.50</td>
<td>0.50</td>
<td>43.7</td>
<td>3.777</td>
<td>6.24</td>
<td>1.831</td>
</tr>
<tr>
<td>0.50 - 0.75</td>
<td>0.75</td>
<td>25.5</td>
<td>3.239</td>
<td>3.92</td>
<td>1.366</td>
</tr>
<tr>
<td>0.75 - 1.00</td>
<td>1.00</td>
<td>24.3</td>
<td>3.190</td>
<td>3.22</td>
<td>1.169</td>
</tr>
<tr>
<td>1.00 - 1.25</td>
<td>1.25</td>
<td>25.2</td>
<td>3.227</td>
<td>3.01</td>
<td>1.102</td>
</tr>
<tr>
<td>1.25 - 1.50</td>
<td>1.50</td>
<td>15.5</td>
<td>2.741</td>
<td>2.76</td>
<td>1.015</td>
</tr>
<tr>
<td>1.50 - 1.75</td>
<td>1.75</td>
<td>15.6</td>
<td>2.747</td>
<td>2.71</td>
<td>0.997</td>
</tr>
<tr>
<td>1.75 - 2.00</td>
<td>2.00</td>
<td>12.7</td>
<td>2.542</td>
<td>2.66</td>
<td>0.978</td>
</tr>
<tr>
<td>2.00 - 2.25</td>
<td>2.25</td>
<td>15.4</td>
<td>2.734</td>
<td>2.66</td>
<td>0.978</td>
</tr>
<tr>
<td>2.25 - 2.50</td>
<td>2.50</td>
<td>7.6</td>
<td>2.028</td>
<td>2.80</td>
<td>1.030</td>
</tr>
<tr>
<td>2.50 - 2.75</td>
<td>2.75</td>
<td>6.1</td>
<td>1.808</td>
<td>2.84</td>
<td>1.044</td>
</tr>
<tr>
<td>2.75 - 3.00</td>
<td>3.00</td>
<td>20.6</td>
<td>3.025</td>
<td>2.77</td>
<td>1.019</td>
</tr>
</tbody>
</table>
similar to that used for the DISTANCE*LOGCNT2 regression:

\[ \text{LOGCNT2} = \text{CONSTANT} + \text{LOGDENS} + (\text{DISTANCE}\times\text{LOGDENS}) \]

where LOGCNT is the natural log of the no. of fires/100,000 acres, DISTANCE is the upper distance value of each 0.25 mile road proximity corridor, and LOGDENS is the natural log of the population density, expressed as the number of people per square mile (lnDENSITY). The DENSITY variable was derived for each road corridor through a GIS overlay; the total number of people in each overlay polygon was calculated and the population density for each road corridor class determined from this.

A summary table of this final regression analysis, and an Analysis of Variance table (both SYSTAT outputs) are shown below. Note that the observed F-ratio (37.584) again is larger than the critical F-ratio value at \( p = 0.001 \) (16.4), so \( H_0 \) can be rejected.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>COEFFICIENT</th>
<th>STD ERROR</th>
<th>STD COEF</th>
<th>TOLERANCE</th>
<th>T</th>
<th>P(2 TAIL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT</td>
<td>2.701</td>
<td>0.401</td>
<td>0.000</td>
<td></td>
<td>6.741</td>
<td>0.000</td>
</tr>
<tr>
<td>LOGDENS</td>
<td>0.751</td>
<td>0.112</td>
<td>0.794</td>
<td>0.845</td>
<td>6.702</td>
<td>0.000</td>
</tr>
<tr>
<td>DISTANCE *LOGDENS</td>
<td>-0.395</td>
<td>0.163</td>
<td>-0.287</td>
<td>0.845</td>
<td>-2.423</td>
<td>0.038</td>
</tr>
</tbody>
</table>

**ANALYSIS OF VARIANCE**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>SUM-OF-SQUARES</th>
<th>DF</th>
<th>MEAN-SQUARE</th>
<th>F-RATIO</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>REGRESSION</td>
<td>10.017</td>
<td>2</td>
<td>5.009</td>
<td>37.584</td>
<td>0.000</td>
</tr>
<tr>
<td>RESIDUAL</td>
<td>1.199</td>
<td>9</td>
<td>0.133</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The derived regression equation is:

\[ \text{LOGCNT2} = 2.701 + 0.751\times\text{LOGDENS}-0.395\times\text{DISTANCE}\times\text{LOGDENS} \]
which transforms to the final equation of:

\[
\text{FIRECNT2} = 14.895 \left( \text{DENSITY}^{0.751-0.395 \text{(DISTANCE)}} \right)
\]

with adjusted R-squared = 0.869 and SEE = 0.365

5.3.4 Summary of Risk Analysis and Future Work

The risk analysis concept presented here is just a starting point. Many independent variables other than the two examined could also be important. These include land ownership, type of fire protection jurisdiction, and demographic data other than population density. Inclusion of these would increase the amount of variation accounted for in the regression model, and would likely result in a more robust model.

The likely existence of co-dependency between independent variables, and the issue of spatially heterogeneous representation of data, would require more advanced statistical analysis techniques than those explored in this study. Additionally, the array of potential independent variables to be explored includes numeric and ordinal data, and dummy variables. To properly address this issue, a more specialized type of statistical analysis, such as a multinomial logit model (Pindyck and Rubinfeld, 1991), would be appropriate.

Other data issues should also be appropriately addressed in future work. Quarter-quarter representation of fire occurrence presented some problems, as did the spatial representation of other layers. In summarizing fire occurrences by quarter-quarter sections, some resolution is lost immediately. Generalizing the location of fires into approximately 40 acre polygons results in a diminished ability to accurately assess proximity effects (roads). A more precise point location for each fire would provide a better basis for analyzing the spatial distribution of fire occurrence.

The size and delineation of census blocks was also a great cause for concern in the analysis. Census blocks are delineated primarily by population density. As a result,
census blocks in urban areas are small, usually a block or less. However, the block size increases in more rural areas; they are immense (up to tens of thousands of acres) in the most remote areas of the county.

Additionally, there is a very sudden transition from small to large census blocks on the periphery of the Seeley Lake community and the Missoula Valley -- right where interface areas lie, and where there are numerous human-caused fires. Thus, the total population of a large rural census block could very well be concentrated in one small portion of the census block. This would be impossible to discern from the data, which simply reports the total number of people within a block, and some key resolution of information is lost.

5.4 JURISDICTIONAL ISSUES AND PROTECTION POLICIES

5.4.1 Jurisdictional Fire Protection Areas and Divergent Responsibilities

One of the interesting characteristics of interface areas of Missoula County, particularly in the Missoula Valley, are the intermingled jurisdictional areas of the wildland agencies and fire service organizations (FSOs). Figure 5.4.1 shows the fire service organization jurisdictional areas, and Figure 5.4.2 shows the wildland agency jurisdictional areas. As a fire service organization’s boundaries expand over time into forested areas, overlapping jurisdictions with wildland agencies inevitably occur.

Such is the case in the Missoula Valley. Here, FSOs historically have been the primary responsible agency in the valley floor, and the wildland agencies were the primary responsible agency in the forested mountains on the periphery. Wildland agencies protected the wild-lands, and FSOs protected populated areas. However, as residential development crept into smaller drainages and slopes bordering the valley over time, a fringe of overlapping protection between FSOs and wildland agencies developed around the periphery of the valley. At the same time, pockets of entirely
unprotected land have been left behind.

The end result is that homes are scattered across overlapping and intermingled wildland and structural jurisdictions. Some homes have only wildland fire protection, others have only structural protection, and some have no fire protection of any kind. In contrast, for most rural areas outside of the Missoula Valley, FSOs show nearly a 100% overlap with wildland agency protection. Here, solid cooperative agreements and working relation-
Fire service organizations and wildland agencies in Missoula County have distinctly different, but overlapping, protection responsibilities as well as jurisdictions. The wildland agencies as a whole are responsible strictly for wildland fire suppression, usually as a part of an overall fire management program that also includes prescribed burning and fuel management. Where structures are threatened, crews may elect to
protect the exterior of a structure. However, no wildland agencies in the county have the equipment, training, directive to suppress structure fires.

The situation is somewhat different with the FSOs. Fire service organizations in Missoula County include four types of legally formed entities; these are described in Table 5.4.1 (MCA, 1993b). One type of FSO found in Missoula County, the volunteer fire company, has no legal jurisdictional area. Another type (fire service fee area) has responsibility to suppress only structural fires (fire service fee area), but usually also suppresses wildland fires. The remaining FSOs have a legal responsibility to suppress all fires (wildland and structural) within their respective jurisdictions. Regardless of the type of FSO, all do some type of wildland fire suppression -- but suppression only.

In the Missoula Valley, the current collection of wildland and structural fire protection jurisdictions are a tangle of boundaries. Boundaries themselves are not always easily changed, and even with the best cooperative efforts between protection agen-

<table>
<thead>
<tr>
<th>FSO Type</th>
<th>No. (ea.)</th>
<th>Legal Responsibility</th>
<th>Legal Jurisdiction?</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire Department</td>
<td>1</td>
<td>All fires</td>
<td>Yes</td>
<td>Encompassed by the legal boundaries of an incorporated municipality.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Supported by a tax levy (through the municipality).</td>
</tr>
<tr>
<td>Rural Fire Dist.</td>
<td>8</td>
<td>All fires</td>
<td>Yes</td>
<td>Formed as a special, single-purpose district in unincorporated portions of</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>the county. Supported by a tax levy.</td>
</tr>
<tr>
<td>Fire Service Fee Area</td>
<td>1</td>
<td>Structure fires</td>
<td>Yes</td>
<td>Formed as a special, single-purpose service area. Supported by a flat fee</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>assessed per structure rather than a tax levy.</td>
</tr>
<tr>
<td>Volunteer Fire Company</td>
<td>1</td>
<td>None</td>
<td>No</td>
<td>No legally defined jurisdictional area, no tax or fee base, and no legal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mandate to suppress any fires. The one volunteer fire company (Swan Valley)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>in Missoula County could not be mapped -- although they provide a valuable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>service to their community.</td>
</tr>
</tbody>
</table>
cies, it is important to have a clear picture as to where dual and single-jurisdictional areas occur, as well as where entirely unprotected areas lie. Particularly in formulating effective emergency response plans and enacting needed mutual aid agreements between neighboring or overlapping jurisdictions.

This was done in the GIS through an overlay of the FSO and wildland agency jurisdictional areas; the resulting layer was then themed to show the types of protection that exist in the composite protection map (Figure 5.4.3).

5.4.2 Large Fires and Multiple Jurisdictions

Not only is a GIS useful for examining jurisdictional issues, but it can provide a means to
assess the potential impact of a large, multi-jurisdictional fire. Given the complexity of jurisdictional boundaries, particularly in the Missoula Valley, and the mix of protection policies and mandates among the affected agencies, this is an important consideration.

Examining the burned area of past large fires in relation to current jurisdictional boundaries underscores this point. In 1991, the LP Mill Fire — a structure fire — burned into wildland fuels, and threatened to spread from a rural fire district to a hillside that had no fire protection that, in turn, bordered the Rattlesnake Valley — protected by four different jurisdictions. Wildfires have no respect for jurisdictional boundaries, and it is essential to be prepared for multi-jurisdictional incidents.

Figure 5.4.4. Large fire history in the Missoula Valley, 1889 - 1991. Fire perimeters are shown against a LANDSAT TM false color composite image for reference. FSO boundaries are also shown in yellow.
Using a GIS can help fire agencies assess the potential impacts of large, disastrous fires. An information layer representing historic large fires (Figure 5.4.4) was overlaid onto the fire protection jurisdiction overlay (Figure 5.4.3). From this, areas of historic large fires were highlighted according to what type of fire protection currently covers that area (Figure 5.4.5).

Against the backdrop of changing politics and cooperative efforts, several major interface fires, and an extensive history of large fires in the county, this part of the study shows the utility of a GIS in sorting through multi-jurisdictional issues. While this simple analysis does not serve as a predictive model per se, it can be used to depict mock scenarios that show just what types of multi-agency complications could realistically arise in the event of a large fire in an interface area. Possible organizational complications can be remedied before they are actually encountered in an emergency situation.

Figure 5.4.5. Overlay of large fire perimeters (Figure 5.4.4) with fire protection jurisdictions (Figure 5.4.3). Fire areas are themed according to the existing (current) protection, per Figure 5.4.3 -- FSO only, wildland only, dual jurisdiction, or none.
CHAPTER 6.

SUMMARY AND CONCLUSIONS

GIS technology greatly enhances our decision-making capabilities, but it does not replace them. It is both a tool box of advanced analysis capabilities and a sandbox to express our creativity and concerns.

-- Joseph K. Berry (1993)

The examples presented in Chapter 5 illustrate ways in which a GIS can integrate a variety of information to bring the wildland/urban interface issue into sharp focus. This study has focused more on the wildland/urban interface issue rather than specific policies surrounding fire protection agencies and political entities. However, agency-specific policies, constraints, and directives, as well as input from the public, could easily be -- and necessarily should be -- incorporated into the process of developing a GIS to focus on specific local issues. Public involvement in particular is an important concern for local governments seeking changes in funding, and the graphic visualization capabilities of a GIS can provide a persuasive tool.

For planning purposes, these types of maps serve primarily as “snapshots” of situations. However, information in a GIS such as this is dynamic. In all reality, a GIS analysis will never really be finished. Risk and hazard will change. Growth will continue. Fire protection jurisdictions will also continue to change, as will the nature of fire protection and agency directives. The following are examples of areas in which future GIS work is warranted, and would enhance the ability of personnel involved in many different facets of the interface issue to deal more effectively with the interface problem.

Temporal Analysis

A GIS can be used to track changes over time, providing a dynamic picture of how a community is evolving and enhancing the planning process for the future. This would be particularly important for hazard and risk. Vegetation changes over time due to fire exclusion, fire occurrence, and land management practices (including hazard mitigation measures). A GIS
would provide a means of assessing how the relative level of hazard is changing, allowing a fire manager to better assess hazard mitigation needs. Similarly, a temporal analysis of fire occurrences, especially human-caused, fires, would help fire personnel measure the effectiveness of prevention and hazard reduction programs. While some fire managers may argue that “You can't put out fires with a computer,” and that GIS is no match for aggressive fire suppression, it should be recognized that the two can go hand in hand.

Spatial Risk Analysis and Modeling
In the past, despite the best efforts of prevention and planning, fire protection has often remained a reactionary business; wait for a fire to start, and then go put it out. Disasters are ever in the making. But by understanding the nature of fire occurrence with better information, we can improve our ability to reduce the occurrence and impact of wildfires.

Spatial Hazard Modeling
Linking a GIS-based fire behavior model with a remote weather station could provide a dynamic, daily assessment of the fire behavior potential, and would thus be of direct use for dispatching and response purposes. It would provide a glimpse of the potential threat to structures in an area, and facilitates the process of setting priorities for hazard mitigation work.

Also, new modeling and visualization technologies have become increasingly sophisticated in their ability to graphically display spatial phenomena. One such example is the FARSITE model (Finney et al., 1994). Other, powerful data visualization programs also show great promise in wildfire-related applications.

Integration of a GIS Into Pre-Suppression Planning
Information supplied by a tool like GIS, used as a pre-planning resource, can dramatically improve the effectiveness of more traditional firefighting methods. The key to solving any problem is in assessing and understanding the nature of the problem. GIS is a powerful tool. It will further the development of focused strategies to reduce the potential loss and tragedies of the future, such as we have experienced in the past.
Appendix A - Glossary of Terms

**Aspect** - The horizontal direction toward which a slope faces, usually expressed as a compass direction (e.g., N, S, E, W) or as degrees clockwise from north.

**Buffer** - A zone of a given distance around a physical entity such as a line, point, or polygon.

**Containment** - To surround a wildfire and any spot fire with a control line as needed, to stop a fire's spread within an area under current and expected conditions.

**Database** - A collection of information that is related by a common purpose or fact. A GIS database contains information about the spatial location and shape of geographic entities as well as their attributes.

**DEM** - Digital elevation model; a digital (computer) file with terrain elevations recorded at the intersections of a fine grid and organized by quadrangle to be the digital equivalent of the digital elevation data on a topographic base map. The representation of topography in a geographic information system from which thematic slope, aspect, and elevation maps are derived.

**Development** - Human-made improvement of property.

**Digital Line Graph** - The geographic and tabular files obtained from the USGS that may include base categories such as transportation, hydrography, contours, and public land survey boundaries.

**Digitizing** - The process of converting an analog image (such as a mylar map) into a digital format that can be used by a computer.

**Extended Attack Incident** - A wildfire that has not been contained or controlled by the initial attack forces and additional firefighting resources are arriving, en route, or being ordered by the Initial Attack Incident Commander.

**Fire Behavior** - The characteristics of an actively burning wildfire such as flame length, intensity, and rate of spread.

**Fire Hydrant** - A valved connection on a piped water supply system having one or more outlets and that is used to supply hose and fire department pumpers with water.

**Fire Prevention** - Activities which reduce the number, or impacts, of wildfires. This includes reduction of fire risks, public education, personal contacts, closures, and regulated use.

**Fire Service Organization** - Any local jurisdiction having responsibility for providing structural, and sometimes structural and wildland, fire protection. In Missoula County; this includes fire departments, rural fire districts and volunteer fire companies.

**Fuels** - Any combustible materials (Class A, or ordinary combustibles) within the wildland/urban interface or wildland/urban intermix. This includes downed woody material, vegetation, and structures.

**Fuel Break** - An area, usually a long strip strategically located, in which vegetative fuels are reduced in volume and maintained to cause a reduction of fire intensity if ignited by a wildland fire.
**Fuel Loading** - The volume of fuel in a given area, usually expressed in tons per acre.

**Fuel Modification** - The removal of fuels, conversion of vegetation to fire resistant species, increased spacing of individual plants, reduction of fuel loading, or lowering of age class.

**Geographic Information System (GIS)** - A computer-based system for capturing, storing, managing, manipulating, transforming, analyzing, modeling, and displaying spatially referenced data for solving complex planning and management problems.

**Hazard** - A source of danger or risk; a combination of fuels and environmental conditions that poses a potential threat of wildfire.

**Head Fire** - A fire that is burning upslope and/or with the wind. Head fires have the highest rate of spread and greatest potential for spotting, crown fires, and other extreme fire behavior.

**Incident Commander** - The person responsible for incident activities, including the development and implementation of strategic decisions, and for approving the ordering and releasing or resources.

**Initial Attack** - The prompt initial fire suppression response to a wildfire. Generally, initial attack involves relatively few resources, and the fire size is small.

**Jurisdictional Agency** - The agency having jurisdiction and responsibility for a geographical area.

**Pixel** - One picture element of a uniform raster layer. Often used synonymously with "cell."

**Polygon** - A vector representation of an enclosed region.

**Prescribed Fire** - A wildland fire, ignited intentionally or unintentionally, that is burning under pre-determined conditions to accomplish a specific land management objective.

**Protection Agency** - A fire service organization or wildfire protection agency assigned the jurisdictional fire protection responsibility of an area.

**Raster Data** - Computer-readable data stored for maps and images, and organized sequentially by rows and columns.

**Rate of Spread** - The rate of advance of the head of a fire over a fuel bed, usually expressed in chains per hour (1 chain = 66 feet).

**Risk** - The probability or chance of an undesirable event occurring.

**Slope** - The upward or downward incline or slant, usually expressed as a ratio, decimal, fraction, or percentage of the vertical rise or fall per horizontal distance. Also called gradient.

**Spatial Analysis** - Analytical techniques associated with the study of the location of geographical entities together with their spatial dimensions. Also referred to as quantitative analysis.

**Spatial Data** - Data in a geographic information system pertaining to the location(s) of geographic entities together with their spatial dimensions and descriptive attributes.
Spatial Risk - A measure of expected fire occurrence over an area; the quantifiable probability of an unwanted event occurring.

Structure - That which is built or constructed, an edifice or building of any kind, or any piece of work artificially built up or composed of parts joined together in some definite manner.

Structure Fire -- A fire originating in, and largely confined to, a structure.

Structure Protection - Activities performed on the exterior of a structure to protect it from a wildfire. This can include vegetation removal, pre-treating the exterior of the structure with water, foam, or other fire retardants, and extinguishment of fires igniting and burning on the exterior of the structure.

Suppression - All the work of extinguishing or confining a fire, beginning with its discovery.

Surface - A representation of geographic information as a set of continuous data in which the map features are not spatially discrete; that is, there is an infinite set of possible values between any two locations. There are no clear or well-defined breaks between possible values of the geographic feature.

Terrain Analysis - Analytical techniques to determine the effect of terrain on a particular operation. Typically involves slope, soil types, and vegetation.

Thiessen Polygons - Polygons whose boundaries define the area that is closest to each point relative to all other points. Thiessen polygons are generated from a set of points.

Timelag - The time period required for wildland fuel moisture content to change in response to a change in environmental parameters (temperature or humidity). One timelag period is the time required for fuels to reach approximately 2/3 of the equilibrium moisture content. 1-Hr. timelag fuels consist of any cured fuels less than ⅛" in diameter; 10-hr timelag fuels are those between ¼ - 1" diameter. 1-Hr. timelag fuels are important in determining the potential for ignition; both are of primary importance in fire behavior.

Topographic Analysis - The analysis of the configuration of a surface, including its relief and the position of streams, roads, cities, etc. Usually subdivided into hypsography (relief features), hydrography (water and drainage features), culture (human-made features), and vegetation.

Vector Data - A coordinate-based data structure commonly used to represent map features. Each linear feature is represented as a list of ordered x, y coordinates.

Wildland Fire - A fire that burns in vegetation, or associated flammable materials.

Wildland/Urban Interface - An area where development and wildland fuels meet at a well defined boundary.

Wildland/Urban Intermix - An area where development and wildland fuels meet with no clearly defined boundary.

Wildfire - An unplanned and unwanted fire requiring suppression action; an uncontrolled fire that is not designated and managed to accomplish pre-determined land management objectives.
Appendix B - Fire Protection Organizations in Missoula County*

Wildland Fire Protection Agencies

Bureau of Indian Affairs; Flathead Agency

Montana Department of State Lands
Southwestern Land Office:
Missoula Unit
Clearwater Unit

Northwestern Land Office:
Swan Unit

U.S. Forest Service
Lolo National Forest:
Missoula Ranger District
Seeley Lake Ranger District
Superior Ranger District

Flathead National Forest:
Swan Ranger District

Fire Service Organizations

Alberton Rural Fire District
Arlee Volunteer Fire Department
Clinton Rural Fire District
East Missoula Rural Fire District
Florence Rural Fire District
Frenchtown Rural Fire District
Greenough-Potomac Fire Service Area
Missoula Fire Department
Missoula Rural Fire District
Ovando Rural Fire District
Seeley Lake Rural Fire District
Swan Valley Volunteer Fire Company

* Protection areas for each entity may lie wholly or partially within the county.
MISSOULA FIRE SERVICES HISTOR Y

Since its establishment as a trading post in the late 1800s, Missoula’s merchants and government officials have tried to encourage population growth in the Missoula valley. Although the lure of the west has always been rugged independence and freedom, people also demanded some of the services and protection offered in the bigger cities. One of the services that attracted new settlers was the promise and provision of fire protection services. As Missoula grew from a small trading post on the new frontier, so did the need for fire services. This chapter describes the establishment of city fire services in the Missoula valley, the development of Missoula Rural Fire District, the history of the resentment between Missoula City Fire Department and Missoula Rural Fire District, and previous attempts to resolve the differences between the two agencies.

The Early Days

In the 1860s, Missoula emerged as a trade center for western Montana. A business district was established on North Higgins Avenue. Mercantile, stables, and residential areas developed as well as several newspapers which chronicled the events of the time. Being in an area of the country where winter outlasts summer by several months of each year, fires were bound to be an issue. When winter set in, businesses and residences alike stoked up fireplaces and furnaces in order to keep warm. As the town of Missoula grew, so did the incidence of chimney fires. In the early years there was no established fire service and residents were forced to draw water from the river or the surrounding creeks and hope for the best results. Sometimes efforts were successful. At other times buildings burned to the ground while residents struggled to douse the flames. In harsh winters, residents were almost helpless in dealing with fires. Often, they could do little more than “hurl curses and ice at it” (Browman, 1993). In 1877, residents attempted to start a bucket brigade. Eighteen people enrolled for a hook and ladder company, but the unit did not come into existence. It is likely that lack of funding may have been the cause.

The need for better fire services increased as the city grew. In 1879, a local newspaper warned readers to “look out for fires.” The paper reported that buildings were packed close together and “few know where our poor excuse for fire apparatus is” (Missoulian, Oct. 3, 1879). At the same time city officials were calling for the development of a reservoir or cistern to be used as an emergency water supply. A water supply reservoir had been built in 1875 by the Missoula Water Works Company, but it did not provide sufficient supply for emergency use. There were no hydrants and pressure was low in the cisterns.

Missoula’s woeful lack of fire services brought calls for a fire company from the Missoula County Times editorial staff. The paper stated that the town needed a fire company and noted

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*Information in this section was supplied by local historian, Mrs. Audra Browman, interview by author, Missoula, Montana, 28 July 1993.*
that "it didn't even have a bucket, let alone a hydrant, or hose" (1884). A meeting was organized in June to discuss the creation of a hook and ladder company. By July, the town adopted the laws necessary for establishing a hook and ladder company. Andrew Logan became the first captain of the Missoula Fire Company, and B.C. Benson and George H. Sweeney became the 1st and 2nd assistants. There is no record whether these men were paid, but it was reported by the Missoulian that the hose company would be limited to 30 members, almost certainly all volunteers. With the establishment of a hose company hydrants were installed in the business district. By 1911, some members of the fire company were apparently paid employees. A Chamber of Commerce publication, circa 1912, reported that Missoula offered the services of a "paid fire department" to town residents.

The Growth Period

The quality of fire services continued to be an issue as Missoula grew. By 1922 Missoula had grown to a city of approximately 13,500. A report written by the Board of Fire Underwriters of the Pacific Municipal Fire Protection in the same year helps to paint a picture of fire services in the early 1900s. It listed the following record of fire alarms and losses between 1917 and 1922:

<table>
<thead>
<tr>
<th>Alarms</th>
<th>Total Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 1st to December 31st, 1917...... 96</td>
<td>$16,179</td>
</tr>
<tr>
<td>January 1st to December 31st, 1918...... 95</td>
<td>11,262</td>
</tr>
<tr>
<td>January 1st to December 31st, 1919...... 109</td>
<td>27,909</td>
</tr>
<tr>
<td>January 1st to December 31st, 1920...... 97</td>
<td>14,988</td>
</tr>
<tr>
<td>January 1st to December 31st, 1921...... 135</td>
<td>30,653</td>
</tr>
<tr>
<td>January 1st to April 30th, 1922...... 29</td>
<td>4,858</td>
</tr>
</tbody>
</table>

The report also discussed the layout of the city, the water system, the make-up of the fire department, and recommendations for improvement of fire protection. Water was supplied through a single, 30-inch, continuous wood-stave pipe and there were 158 public hydrants in town. It was reported that while the hydrants were in good condition, the pressure and flow was poor. The make-up of the fire department consisted of "nine full paid men, three call men, a chief and an assistant chief" (Board of Underwriters report, 1922). Fire service employees were allowed 15 days annual vacation and were not allowed to leave the city when off duty without the permission of the chief. Fire apparatus was motorized and consisted of one chief's car (a Ford Roadster with a truck body), one American-La France triple combination pumper, hose, and chemical truck, one Seagrave automobile combination hose and chemical truck, one Seagrave trussed frame ladder truck, and one second size Nott steamer. All of the apparatus ran out of one station which was located on the corner of Stevens and Main Street in the heart of the business district. The report concluded that "fire protection had not increased proportionately with the growth of the city, [and] sufficient appropriations are not made to provide an adequate force, the number of paid men being too small to man the apparatus in service."
also cited a concern about the rapidly growing south side of the city and the fact that there was only one fire station. Recommendations in the 1922 report included the building of a southside fire station, an increase in manpower, and construction of a drill tower to insure the quality of training of fire-fighters.

A representative from the Board of Fire Underwriters of the Pacific Coast named Charles W. Cook addressed the Kiwanis club in 1923 on the condition of fire services in Missoula. The fire-fighting infrastructure received low marks from Cook: “The fire department we found even more deficient than the water system... this is not a reflection on the men, for I commend them upon the excellent work they are doing considering the condition under which they are laboring” (June 7, 1923). This situation prevailed for several years to follow. There were hard-working, efficient employees in the Missoula City Fire Department, but apparatus and manpower were woefully lacking. In a May 7th, 1925 news article, Chief James T. Cranney wrote to the residents that “Missoula, of course, has a good fire department. Perhaps the size of its personnel and the extent of its equipment are measures of our ability to pay for, but it seems to us that there should never be any thought of reducing the efficiency and strength of the department in any way, but that, rather we should be planning all of the time to make the department even stronger. This would be the best sort of fire insurance.”

The Board of Fire Underwriters recommended again in 1927 that Missoula upgrade equipment, build a new station south of the Clark Fork River, increase manpower, enact a new building code, and replace the water supply system (news article, December 9, 1927). The fire department consisted of 12 paid staff members while the report recommended 54. Missoula continued to grow, but the fire department remained small. There were many fires and fire-fighters did the best they could with limited manpower and apparatus.

When a housing boom hit Missoula in 1929 the Board of Fire Underwriters began an ad campaign which described the lack of adequate fire services and the increasing probability of catastrophe in Missoula. This reflected a movement to make the public more aware of the low level of staffing and equipment in the fire service. 1932 brought a ten percent cut in salary to the fire department due to the Depression, but by 1933, there was renewed hope for improved fire services. A local newspaper reported that “Missoula will be the scene of considerable building activity... as contractors and others engaged in the building trades begin to see the light in clouds of depression” (news article, April 30th, 1933). Missoula Fire Department salaries were restored to 1931 levels and the city council granted permission to improve fire services by repairing the fire station.

Missoula continued to experience a housing boom throughout the 1930s and the city government began to consider annexation of newly developing residential areas as a means of insuring fire protection and other services. Houses within city limits were covered by city fire services, but residents living beyond the borders were left without fire protection. Annexations, although seen as necessary by city government officials, were viewed as hostile take-over attempts by rural residents.

One of the developing areas of the Missoula valley which the city wanted to annex was called Orchard Homes. Because the city fire department could not legally respond to fires outside of the city limits, there was little or no fire protection for rural residents. As a possible solution to the problem, a group of residents known as the Orchard Homes County Life Club set about trying to organize a volunteer fire department in March of 1939. A Missoulian editorial suggested that a fire district be created and a city-county fire truck be used for rural fires. The Orchard Homes Volunteer Fire Department began operating when several people from the County Life Club mounted two 35 gallon and one 40 gallon chemical fire extinguishers on a Ford truck. Herbert Hughes was appointed Fire Chief and
the Missoula City Fire Department promised to train volunteers once the department became more organized. The Orchard Homes Volunteer Fire Department responded to its first house fire in 1940.

The Missoula City Fire Department continued to struggle with staffing and equipment throughout the 1940s. In 1941, S. R. Waugh, a representative from the Board of Fire Underwriters commented that "the fire department personnel here is fine, but even the finest watchmaker can't make a watch without tools" (Missoulian, Dec 4, 1941). There still was no fire station on the south side of the Clark Fork river and only one pumper truck maintained by the Orchard Homes residents.

1942 brought a sudden and unexpected end to the Orchard Homes Volunteer Fire Department. On February 21, the Department responded to a fire at a local lumber yard. After extinguishing the fire, according to the report of city fire chief A. L. Quinn (Missoulian, Feb. 22, 1942), the department returned to the garage they had built to house the pumper. It was a cold night and the hoses had frozen. In an effort to thaw the hoses, the fire-fighters stoked the stove in the garage and went home. Some time during the night, the garage caught fire. The city fire department came to extinguish the flames, but the pumper was ruined. The fire brought an end to the Orchard Homes Volunteer Fire Department.

Meanwhile the city of Missoula continued efforts to improve its fire infrastructure. In 1942 the city sought to purchase new equipment through a $35,000 bond issue, but World War II brought an end to that plan. Again, in 1949, the calls for a new south side fire station arose in Missoula. The city proposed to build a station on Stephens Avenue where Sacajawea Park stood, but the neighbors protested and the effort died. Finally, the city approved the funding of $166,000 for the building of two new fire stations in 1950, one on Pine street in the downtown area and the other on the south side of the river on Mount avenue. Both stations were built and opened in 1954. The city had its south side fire station thirty-two years after it was first recommended. The city built one more station on the south side of the river in 1977. Located on 39th Street, it was initially staffed with two person crews in 1977.

**Missoula Rural Fire Comes Into Existence³**

The city of Missoula continued to expand into various valley pockets as the population increased, but areas outside of city limits still suffered from a lack of fire protection. Farmland was being subdivided and houses built. Missoula was becoming more urban as orchards became small neighborhoods. In 1960 the City of Missoula once again proposed to annex the Orchard Homes area of the valley. After the Orchard Homes Volunteer Fire Department failed, residents in the Orchard Homes area had been serviced by one 1939 engine which was located at Fort Missoula (on the south side of town). The matter of annexations is not one which is easily understood, but it does tend to raise the ire of people in the proposed annexation area. That was the case in Orchard Homes in 1960. Residents concerned about higher taxes and loss of rural character circulated petitions to protest the annexation. At the same time, residents proposed the creation of a rural fire district in order to protect the increasing residential areas in the rural sections of the valley. The protest succeeded and in late 1960 Missoula Rural Fire District was formed by petition of rural residents. The district initially covered an area of approximately five square miles from south of the Clark Fork River to the Bitterroot River.

The Missoula Rural Fire District was governed by a five person board of trustees. The first board hired a chief and two assistant chiefs. The rest of the organization consisted of 42 volunteers. The first fire station was located at 2135 South Third Avenue West and was equipped with a borrowed engine. Six months later, MRFD received a water tanker and a first line engine for the Third Avenue station.

MRFD had outgrown its station by 1962 and received enough financial support from district

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³Chief Bill Reed, Missoula Rural Fire District, interview by author, Missoula, Montana, 17 August 1993.
residents to build a new station. In October 1963 Missoula Rural Fire District moved into a new building on the corner of South avenue and Reserve street. As the district expanded its boundaries over the next few years, the need for more staff arose and in 1968 three more fire-fighters were hired as full-time employees. The number of volunteers increased as well to 80. A legal opinion in the 1940s stated that the Missoula City Fire Department could not respond outside of city limits. As a result, there were many areas within the Missoula valley that still had no fire protection. Some of these areas were the Rattlesnake Canyon to the north, Bonner to the east, Lolo to the south, and the airport area to the west. As it became evident that residential areas were expanding in those directions, Missoula Rural Fire began its expansion of fire protection services to additional areas.

The first expansion occurred in 1968 with the addition of a fire station in the Rattlesnake area and another station by the airport. The Rattlesnake was staffed primarily by volunteers, but in the 1970s MRFD hired a part-time paid staff to man the station for eight hours a day, five days a week. In 1971, MRFD opened a fourth station in Bonner and hired three more full-time employees. Station five in Lolo was opened in 1973, and finally in 1982, station six opened in a residential section west of town on Mullan Road. Between MRFD, Clinton Rural Fire District, Frenchtown Rural District, Florence Volunteer Fire Department, and Arlee Volunteer Fire Department, most of the Missoula valley had some kind of fire protection by 1982. The U.S. Forest Service and the Department of State Lands also offered fire protection in the case of wildland fires. The animosity which developed between Missoula Rural Fire District and the Missoula City Fire Department, as well as attempts to resolve some of the differences are discussed in detail in the following section.

The Rift

When the Missoula valley was relatively unpopulated, there was a clear need for two fire departments. Rural areas fell beyond the range of city fire services. The Missoula City Fire Department was mandated to cover only city residents. As population density increased on the valley floor, demand for fire services also increased. Both MRFD and MCFD increased staffing and services in an attempt to better serve the rising population. Over time, an uneasy relationship developed between the two departments. In order to better understand Missoula’s current fire services situation, it is important to investigate the roots of the troubled relationship between MRFD and MCFD.

Pinpointing the exact cause of the animosity between the two fire departments or when it began is difficult. The fact that Missoula Rural Fire District began as a protest to annexation clearly set the stage for dispute. The growth of the two agencies also contributed to the development of separate identities. Missoula City Fire Department grew from a paid staff of three people and one station to a paid staff of 65 people and three stations (with an additional station being built currently). Missoula Rural Fire District grew from a staff of three paid employees, 42 volunteers, and one station to a staff of 26 paid employees, 78 volunteers, and six stations. Both departments developed strong senses of pride and integrity and became strong political voices in the community.

The rift between the two agencies widened as political boundaries between the city and county of Missoula changed over the years. As a result of annexations by the city, neighborhoods that once fell under rural fire protection became part of the city’s fire protection area. Annexed areas were often located adjacent to a Missoula Rural Fire District station, but because there was no agreement between

*Information in this section was derived from several sources, including Missoula City Fire Department scrapbooks, Missoula Rural Fire Department scrapbooks, and phone interviews with relatives of previous fire department — employees.
MCFD and MRFD, those areas had to be serviced by the Missoula city fire services. Conversely, rural residential areas nearly engulfed by city areas could not be serviced by the city. Fire agency administrators on both sides dug in and tried to protect their "turf."

Staffing and funding patterns created friction as well. Each agency sought to increase staff in order to meet standards set by the National Fire Protection Association. Missoula Rural Fire District relied on volunteers while Missoula City Fire Department utilized paid firefighters in responding to calls. The question of whether MRFD use of volunteers legitimately substituted for a paid department increased tension between the two fire agencies. Both sides engaged in "name calling," arguing over which department was better ready to respond to emergency situations. In addition, Missoula Rural Fire District made a conscious effort to fight city annexations because of the loss of territory and revenues that would result. Although these efforts were not aimed at the city fire department, they nonetheless created an adversarial relationship between the two departments. As each agency dug in, public safety sometimes became a casualty. For example, a house burned down just outside of the city limits because the city fire department would not cross the boundary. Fire department employees were not at fault. They had been told by city officials not to respond to calls outside of the city limits. City officials stated that the fire department was funded by city residents and responsible only to them.

Political intervention also widened the gap between fire services. Each agency is governed by a different political body and bound by a different set of regulations. City fire departments in Montana are established by ordinances created by city councils, while rural fire districts are established by petition of the taxpayers. The city of Missoula is required by law to provide a paid, full-time fire department, whereas Missoula County is not. The Missoula Rural Fire Department is governed by an elected board of trustees while the city fire department is governed by the city council. The two agencies serve different political masters despite the fact that they exist side by side. The uneasy twist of politics and fire services has created a balancing act between city administrators, fire officials, board members, council members, and county commissioners that a high wire performer would envy. Powerful forces within the Missoula city government have strictly maintained that MCFD's mandate is to provide services only to tax paying city residents, while the MRFD board has insisted on continued growth. The inability of politicians to look beyond what is politically gainful has played a key role in the development of the rift between fire service providers in the Missoula valley.

Finally, controversial administrative decisions regarding protection of certain valley areas have also created increased feelings of distrust between fire service providers. For example, a northern section of the Missoula valley, called The Rattlesnake had been served by the Missoula Rural Fire District since 1968. In 1990, the city of Missoula annexed most of the populated areas of the Rattlesnake valley. A mix of MCFD and MRFD coverage resulted, creating confusion for service providers and residents alike. The setup remains controversial to this day.

Previous Resolution Efforts
There have been numerous documented disagreements between fire chiefs, mayors, council members, and residents in regard to fire protection. Several people have made efforts to resolve some of the differences over the years. In 1984, for example, a mutual aid agreement was worked out between Missoula Rural Fire District, the U. S. Forest Service (Lolo National Forest), the Department of State Lands, and several rural fire services allowing each agency to respond to a fire emergency within any jurisdiction. MCFD, however, did not enter into the agreement.

Perhaps the most extensive recommendation for resolving the confusion in the Missoula valley came in 1986. In an effort to clarify the roles of each fire entity in the Missoula valley, a focus group
comprised of local citizens, fire officials, business leaders, and elected officials was formed. The group, called the Missoula Citizens’ Fire Master Planning Committee, released a report entitled Missoula Fire And Emergency Services Master Plan. The committee offered as a primary recommendation the creation of “a unified district encompassing all of the areas presently served by the East Missoula Rural Fire Department, the Missoula City Fire Department, and the Missoula Rural Fire Department.” The committee concluded, “This unification is the only practical solution to district boundary problems and would result in the most efficient use of equipment, stations, and manpower” (pg. iii, 1986). The committee also recommended full support for enabling legislation to allow a unified district. Alternatives such as an automatic aid agreement, automatic aid for special targets, and mutual aid were offered if the primary recommendation could not be fulfilled. The report also detailed recommendations on several aspects of fire services, including recommendations on fire and emergency services; training; disaster planning; University of Montana planning; station, training facilities, and apparatus; insurance; citizen participation; administration and finance; government and private agencies cooperation; and fire safety division. Although many hours were spent in developing the 1986 Master Plan, no fire agency followed through on the recommendations. According to current Missoula Fire Chief, Chuck Gibson, the Missoula City Council opposed a unified fire district because of a fear that current levels of service might not be maintained if fire services agencies unified.

A second attempt at unification occurred in 1987 when Paul Laisy, an administrator at MRFD, proposed an automatic aid response system between fire agencies. The Missoula City Council and the Mayor of Missoula, Bob Lovegrove, again opposed such an agreement. The Mayor stated that “One of the interests (in not agreeing) is that it reduces the rationale for annexation” (Missoulian, Nov. 29, 1987). Politics prevailed over public safety. In 1989, two MRFD volunteers, Kelly Close and Jon Agner, attempted to initiate a merger between the Missoula City Fire Department and the Missoula Rural Fire District. The Board of Trustees of MRFD supported the initiative while the Missoula City Council opposed it. The City Council explained that county residents should not receive services from the city because they do not pay for those services. City officials said that, “city residents would pay for equipment that would benefit county residents and that the quality of protection might decline” (Missoulian, Nov. 2, 1989). The authors of the merger initiative attempted to place a proposal on the November, 1989 ballot, but decided to shelve the measure after meeting with resistance from MCFD union representatives.

It took the death of an employee of the Thatcher Chemical Company in Missoula and a threat of a lawsuit in 1992 to spur the enactment of an automatic aid agreement between Missoula City Fire Department and Missoula Rural Fire District. A Thatcher employee suffered a heart attack while at work. The building fell within Missoula Rural Fire’s boundary so MRFD was dispatched to the incident. Dispatchers did not call city fire-fighters due to the lack of an automatic aid agreement between agencies. The woman subsequently died. Investigators determined that city fire-fighters could have reached the woman sooner than MRFD, possibly saving a life. Following the investigation, City and County officials signed an automatic aid agreement allowing for simultaneous dispatch of MRFD and MCFD service providers. The goal was to provide the quicker service for the public good. The automatic aid agreement continues at this time.
Appendix D

Southwestern Montana

1994 MULTI-AGENCY ANNUAL OPERATING PLAN

for Cooperative Fire, Wildland / Urban Interface, Wildfire Prevention, Wildfire Protection, Interagency Training programs and Public Information

Approved Master Agreements

This operating plan is entered into by and between the Missoula County Fire Protection Association; and the Missoula Ranger District, Seeley Lake Ranger District, and Ninemile Ranger District, Lolo National Forest, hereinafter called USFS, and the Missoula Rural Fire District, the Seeley Lake Rural Fire District, Florence Rural Fire District, Clinton Rural Fire District, Frenchtown Rural Fire District, East Missoula Rural Fire District, and the Missoula City Fire Department, hereinafter called Cooperators, and the Missoula Unit, Clearwater Unit, Southwest Area, Montana Department of State Lands, hereinafter called DSL, under the provisions of the Master Agreement FS-01-91-35 dated September 25, 1991, and the Cooperative Fire Management Agreement between the State of Montana, and sub-contractor Lolo National Forest and the Missoula Rural Fire District, dated November 30, 1981; the Cooperative Fire Control Agreement between the State of Montana and the Seeley Lake Rural Fire District, dated May 21, 1985; and the Cooperative Fire Agreement between the State of Montana and the Florence Rural Fire District, dated May 1, 1985; and the Cooperative Fire Agreement between the State of Montana and the Clinton Rural Fire District, dated September 19, 1989; and the Cooperative Fire Agreement between the State of Montana and the Frenchtown Rural Fire District dated September 19, 1989; and the Cooperative Fire Agreement between the State of Montana and the East Missoula Rural Fire District dated June 6, 1991; and the Cooperative Fire Agreement between the State of Montana and the Missoula City Fire Department dated May 1, 1990; and the Cooperative Fire Agreement between the State of Montana and the Greenough Potomac Fire District dated April 2, 1993. The parties hereto agree as follows:

PURPOSE:

The purpose of this Operating Plan is to define operating procedures and responsibilities within the framework of the Cooperative Fire Management Agreements referred to above.

I. EXCHANGE ZONES

A. The exchange zones are those areas within the jurisdictional areas of the agencies signatory hereto. Maps which outline the exchange zones for each agency are attached to the Cooperative Fire Management Agreements referred to above.

B. Requests for Assistance - Request for assistance within the exchange zones as outlined must be approved by:

DEPARTMENT OF STATE LANDS:

Clearwater Unit - Fire Specialist or Unit Supervisor
Missoula Unit - Fire Specialist or Unit Supervisor
LOLO NATIONAL FOREST:

All Ranger Districts - Fire manager or fire Duty Officer

COOPERATORS:

Missoula Rural Fire District - Duty Chief
Seeley Lake Rural Fire District - Duty Chief, District Manager or Assistant Fire Chief
Florence Rural Fire District - Fire Chief or Assistant Fire Chief
Clinton Rural Fire District - Fire Chief or Assistant Fire Chief
Frenchtown Rural Fire District - Fire Chief or Assistant Fire Chief
East Missoula Rural Fire District - Fire Chief or Assistant Fire Chief
Missoula City Fire Department - Fire Chief or Assistant Fire Chief
Greenough Potomac Fire District - Fire Chief or Assistant Fire Chief

II. MUTUAL ASSISTANCE ZONES

A. Mutual assistance zones are those areas within one (1) mile of either side of the jurisdictional boundary for each agency within the framework of the Cooperative Fire Management Agreement.

B. Requests for Assistance - Request for assistance within the mutual assistance zones are automatically approved and should be immediately referred to the appropriate dispatch center:

DEPARTMENT OF STATE LANDS:
Clearwater Unit Dispatch Center - 793-5757
Missoula Unit Dispatch Center - 542-4343

LOLO NATIONAL FOREST:
Dispatch Center - 329-3857

COOPERATORS:
911 Emergency Communications Center - 523-4760

III. INCIDENT REPORTS

In the event any agency suppresses a fire on land administered by another agency, it will furnish the benefiting agency a copy of the preliminary incident report within 10 days after the fire is declared out.
IV. **FIRE CAUSE INVESTIGATION**

It will be the primary responsibility of the agency on whose protection area the fire originates to undertake a Fire Cause Investigation. This does not preclude joint action and in those instances when initial action or suppression is made on protection areas of the other, the initial attack force will immediately attempt to gather and preserve evidence pertaining to the cause of the fire.

V. **CLOSURE AND RESTRICTIONS**

If the need develops for a closure or restrictions affecting any of the agencies, all parties to this agreement shall notify the others of their interest to institute, modify or remove closures or restrictions. All conditions of such closures or restrictions will be mutually agreed upon prior to such closure.

VI. **WILDLAND/URBAN INTERFACE & COMMUNITY FIRE PROGRAMS**

In an effort to improve local awareness of wildland/urban interface and fire safety, programs will be developed to address specific issues identified by the agencies signatory hereto. Agencies and departments may assist one another and bill the agency for services or materials provided as mutually agreed upon by both parties.

VII. **TRAINING**

All parties to this operating plan agree to exchange training opportunities, including trainers, trainees and materials and support for the FETN Interagency Training Program. All local training that is multi-agency in nature and sponsored by one of the parties to this agreement will be coordinated and made available to all agencies on a reimbursed cost-share basis. The Missoula County Fire Protection Association Training Working Team will serve as the Interagency Training Coordination Group. Agencies may utilize the expertise of individuals for certain training opportunities or sessions. If this occurs, the agency may reimburse the agency for travel and associated costs, if such costs are deemed necessary by both parties.

VIII. **COMMUNICATIONS**

A. Radios

By the terms of this agreement, each party agrees to permit the others to utilize their radio frequencies in providing assistance for emergency purposes. (See Mobilization Directory)

B. Computers

By the terms of this agreement, each party agrees to permit the others to utilize computer systems. Agencies using systems will be furnished call signs/passwords. For utilization of specialized computer equipment, such as graphic capability etc., agencies may, if agreed to, bill the using agency for computer use fees, as agreed upon by both parties.

C. Telephone/Pagers/Cellular Phones

By the terms of this agreement, each party agrees to keep their phone and pager numbers updated in the Mobilization Directory.
IX. FACILITIES

Each agency shall make their facilities available upon reasonable request for use as a meeting site or training facility. Use of agencies' facilities for storage of fire apparatus shall be negotiated between agencies and covered by the proper agreements.

X. PERSONNEL AND EQUIPMENT

Each agency shall maintain in the Mobilization Directory, a list of personnel and equipment available to other agencies.

The structural fire Cooperators shall have their equipment inspected and signed up by the DSL prior to March 15.

XI. OPERATIONS

When one agency requests assistance from another, the sending agency shall dispatch only those personnel who meet or exceed the minimum requirements for qualification and certification by each agency according to the Wildland Qualification and Certification Guide (ICS 310-1).

On mutual aid incidents within the local area, local standards will apply. These standards are the minimum training and fitness requirements which are recognized by each fire agency for their own jurisdictional area.

When Local Government Forces (LGF) are hired by the USFS and/or DSL for wildfire suppression, and payment is made for their assistance, the guidelines in the DSL Fire Suppression Manual (section 933.3) will be used. These guidelines require minimum fitness levels for in-state and out-of-state dispatches. The guidelines also establish minimum training levels for structure protection and wildland fire suppression assignments.

The use of Red Cards to document an individual's training and fitness levels is encouraged. Wildland agencies will recognize Red Cards issued by local departments for ICS positions up to the Single Resource Boss level (Engine Boss). Red Cards for ICS positions of Strike Team Leader and above will be issued by the DSL Southwestern Land Office using the Montana DSL Fire Management Qualifications and Certification Guide (DSL310-1).

At the time of a request for assistance during a wildfire, the assisting agency (ies) shall dispatch the nearest available resources to the requesting agency's incident.

At the time of a request, each party may assign an officer that supervises the activities of his/her agency's resources.

It shall be policy for the party requesting assistance to release the assisting agency from emergency duties as soon as practicable and mutually desired.

All agencies will operate using the Incident Command System.

The first arriving officer from any agency shall assume the role of Incident Commander and shall transition to the Command personnel from the responsible agency upon their arrival and briefing.
In the event that a Cooperator’s Incident Commander (Multi-leader, Multi-resource, or Multi-division) determines that a wildland fire is on or threatening DSL or USFS land prior to the arrival of a DSL or USFS Incident Commander, the Cooperator’s Incident Commander may order sufficient resources to handle the incident through the responsible agency’s dispatch center.

Out of area assignments for the Cooperator’s overhead, firefighters and equipment will be ordered through normal DSL or USFS channels and will be billed through and/or paid by DSL.

Requests for assistance for the Cooperator’s overhead, firefighters and equipment will be ordered through normal DSL or USFS channels and will be billed through and/or paid by DSL.

Annually, the pre-planned dispatch plans shall be updated and reviewed by the cooperating agencies.

All agencies signatory hereto agrees to equip, staff and maintain the Interagency Incident Command Post trailer as necessary.

XII. **REIMBURSEMENTS**

Reimbursements made under the provisions of this operating plan shall be in accordance with the terms of the following:

A. Non-fire reimbursement will be billed direct to the parties involved.
B. Fire reimbursement will be billed through the Department of State Lands.

This agreement incorporates by reference the **COOPERATIVE FIRE MANAGEMENT AGREEMENT** between the USDA Forest Service and the State of Montana, Department of State Lands FS-01-91-35 dated September 1991.

Reimbursements to the Cooperators under this agreement shall be by the rates and terms established in the State of Montana Fire Business Handbook.


The parties signatory hereto agree, in areas not identified in this plan, that if personnel, overhead and equipment are used on other agencies’ incidents, that agency will bill for all direct costs incurred.


The agencies agree that they shall furnish personnel and equipment to the other agencies upon request. Requests will be honored as current conditions permit. All such efforts shall be reimbursed by the requesting agency.

XII. **EFFECTIVE DATES.**

This annual operating plan is in effect from January 1, 1994 to December 31, 1994.

**OPERATING PLAN APPROVAL:**

**Department of State Lands, Southwest Land Office**
By: ________________________________ Date: __________
Title: Area Manager

**Department of State Lands, Northwest Land Office**
By: ________________________________ Date: __________
Title: Area Manager

**Bureau of Indian Affairs, Flathead Reservation**
By: ________________________________ Date: __________
Title: Superintendent

**Bureau of Land Management, Garnet Resource Area**
By: ________________________________ Date: __________
Title: Area Manager

**Lolo National Forest**
By: ________________________________ Date: __________
Title: Forest Supervisor

**Bitterroot National Forest**
By: ________________________________ Date: __________
Title: Forest Supervisor

**Clearwater National Forest**
By: ________________________________ Date: __________
Title: Forest Supervisor

**Cooperator - Missoula Rural Fire District**
By: ________________________________ Date: __________
Title: Chief Executive Officer

**Cooperator - Florence Rural Fire District**
By: ________________________________ Date: __________
Title: Fire Chief

**Cooperator - Seeley Lake Rural Fire District**
By: ________________________________ Date: __________
Title: Fire Chief

**Cooperator - Clinton Rural Fire District**
By: ________________________________ Date: __________
Title: Fire Chief
Cooperator - Frenchtown Rural Fire District
By: ________________________________ Date: ____________
Title: Fire Chief

Cooperator - East Missoula Rural Fire District
By: ________________________________ Date: ____________
Title: Fire Chief

Cooperator - Missoula County Fire Protection Association
By: ________________________________ Date: ____________
Title: Chair, Board of Directors

Cooperator - Missoula City Fire Department
By: ________________________________ Date: ____________
Title: Fire Chief

Cooperator - Greenough Potomac Fire District
By: ________________________________ Date: ____________
Title: Fire Chief

Cooperator - Plains Volunteer Fire District
By: ________________________________ Date: ____________
Title: Fire Chief

Cooperator - Thompson Falls Volunteer Fire District
By: ________________________________ Date: ____________
Title: Fire Chief

Cooperator - Superior Volunteer Fire District
By: ________________________________ Date: ____________
Title: Fire Chief
Rattlesnake residents protest annexation

By DONNA SYVERTSON
of the Missoulian

About 100 residents of the Rattlesnake Valley area sent a letter to the Missoula City Council asking that the city not annex the Rattlesnake Valley be annexed. The letter was signed by about 100 angry residents about a month into the meeting to discuss the annexation proposal.

City officials said the annexation proposal was made by the city to provide essential services.

The letter said the residents would support the annexation if it were done “on a realistic and comprehensive manner.”

The letter was sent to the council on April 12, 1990.

Missoulian, Nov. 28, 1989

Council OKs annexation plans

By BETTY BRENNAN

After more than an hour of listening to about 100 angry Rattlesnake residents protest the city’s annexation decision, the council voted to do so anyway.

The council’s vote was a “resolution of intent” to annex most of their valley Monday night, the council voted to do so anyway.

The council’s vote was a “resolution of intent” to annex most of their valley Monday night, the council voted to do so anyway.

The council also voted to proceed with the annexation of Wapiti/Bellevue, a decision that no other protestor at the meeting, as well as a neighborhood north to Reserve Street.

While the city has been negotiating for some time with the Wapiti/Bellevue residents about annexation and sewer, Rattlesnake residents did not find out they were to be annexed until last week when they received a letter informing them of the city’s plans. The letter included a comparison of city and county taxes, and said that Rattlesnake residents’ taxes would increase about 18 to 21 percent.

But the move to break the camel’s back was a letter written by Roy Clark and Joe Agner, two volunteer firemen in the Missoula Rural Fire District. The letter stated that instead of being annexed, the Rattlesnake area would have a central sewer in the valley and that response time could in fact be lengthened.

Mayor-elect Dan Kemmis said it is his intention to “negotiate an agreement with the rural fire district that will maintain at least the status quo level of protection for the immediate future.”

Rattlesnake residents praised the county for its fine services and demanded to know what additional services they would receive for their increased tax burden.

Council members responded by talking about the danger of annexation. Missoulian, Nov. 21, 1989

Annexation

Rattlesnake residents ask for truth, a little respect

By MIKE BENNETT

At present, we are being asked to take on faith both the level of service and the ultimate cost — this from a government body that has yet to give us any reason to trust it.

The residents have until Dec. 18 to file their protests.

Bill Hannon is a spokesman of the Rattlesnake Annexation Committee.

Missoulian, April 12, 1990

Appendix E - Missoulian Articles Pertaining to the 1989 Rattlesnake Annexation
City taken to task

Rattlesnake residents chide officials for not doing annexation homework

BY DONNA EVERTSON

Almost 300 Rattlesnake Valley residents told Missoula city officials Friday night that they resent the way city officials are going about annexing them into the city and accused officials of not doing their homework before taking the process.

Mayor-elect Don Kemrick responded that the city should have given people in the Rattlesnake "a sooner opportunity" than they've had to participate in the annexation process.

If the city goes ahead with the annexation as initially planned, it would cost to pay for sewer hook-ups and the city would have to pay for property taxes.

"Let's all sit down calmly, neighbor to neighbor," he concluded to a crowd.

In a meeting after city officials held a meeting of the Rattlesnake School District, Missoula City Commission Chairwoman Evans told the commission that the city had not been notified of the city's plans to annex the Rattlesnake.

Mayor Kemrick said the city had planned to annex the Rattlesnake for years and had many plans for it in its 1989-90 budget. But it served by the city is lower than expected.

"I'm cautiously excited," Evans said.

"I'm pleased with it," Mayor Kemrick said after the meeting. "I think we've come up with a solution through the 'whole' method."

The city is proposing to annex a portion of the Rattlesnake that is served by the city's sewer system. It is also proposing to annex other sections of the valley by surrounding them with properties already annexed within the city limits.

Evans said the city's methods are correct because some of the property the city plans to annex is not served by the city's sewer system.

"Let's do this letter right, neighbor to neighbor," Evans continued to the gathering.

During the 1-hour meeting, the city's representative was asked about the plans for annexing the Rattlesnake and how the city was going to help residents with the process.

"We have to do this letter right," Evans said. "We have to do this letter right, neighbor to neighbor."
## Appendix F - Summary of Missoula County (MSLACO) Map Layers

Summary of Missoula County (MSLACO) map layers. Layer types indicated are vector (V), surface raster (S), and polygon raster (P).

<table>
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Appendix G - Summary of Rattlesnake (RATTLE2) Map Layers

Summary of Rattlesnake Valley (RATTLE2) map layers. Layer types indicated are vector (V), surface raster (S), and Polygon raster (P).

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Appendix H - Legal Description of the Missoula County Boundary

Missoula County. Beginning at the intersection of the center of the channel of the Flathead river with the south line of the north tier of sections of township twenty-one (21) north; running thence southerly along the center of the main channel of the said Flathead or Pend d'Oreille river to its intersection with the south boundary line of township nineteen (19) north, range twenty-one (21) west, said point being approximately two (2) miles east of the southwest corner of said township; thence east on the line between townships eighteen (18) and nineteen (19) north, to the point where said line intersects the line between ranges twenty (20) and twenty-one (21) west; thence south on said line between ranges twenty (20) and twenty-one (21) west, to the summit of the range of mountains dividing the waters of the Missoula and Pend d'Oreille or Flathead rivers; thence westerly along said summit of the Coeur d'Alene mountains, to a point where said summit intersects the summit of the watershed dividing the waters of the Missoula and Clarks Fork rivers; thence westerly along said summit dividing the waters of the Missoula and Clarks Fork rivers to the northeast corner of section five (5), township seventeen (17) north, range twenty-five (25) west; thence running south to the southwest corner of section nine (9), township seventeen (17) north, range twenty-five (25) west; thence running east to the southeast corner of said section nine (9); thence running south to the southwest corner of section fifteen (15), township seventeen (17) north, range twenty-five (25) west; thence running east to the northeast corner of section twenty-four (24); township seventeen west; thence running south to the southeast corner of section thirty-six (36), township twelve (12) north, range twenty-four (24) west; thence running west to the northwest corner of section six (6), township eleven (11) north, range twenty-four (24) west; thence running south to the Montana-Idaho state line; thence running in a general southeasterly direction following said line to the intersection with the south line of township eleven (11) north, range twenty-two (22) west; thence running east along the line between townships ten (10) and eleven north, to an intersection with the center of the channel of Rock creek; thence running in a northerly direction following down the center of the channel of Rock creek to the center of the channel of the Hell Gate river; thence running in an easterly direction up the center of the old original channel of said river as the same existed at the time of the creation of Missoula county, to an intersection with a line projected due north from the top of Medicine Tree hill, said natural monument being located in township eleven (11) north, range fifteen (15) west; thence running north along said line to the top of the divide between the Hell Gate and Blackfoot rivers; thence running in an easterly direction following the summit if said divide to its intersection with the line of township twelve (12) north, range fourteen (14) west; thence running north along the line between ranges thirteen (13) and fourteen (14) west, observing the offsets and corrections thereto to the northeast corner of township sixteen (16) north, range fourteen (14) west; thence running west along the fourth standard parallel north to an intersection with a line hereto described as being projected due north from the top of Medicine Tree hill; thence running north along said line to an intersection with the south line of the north tier of sections of township twenty-one (21) north, range fifteen (15) west; thence running west along the south line of the north tier of sections of township twenty-one (21) north to the place of beginning. The county seat is Missoula, Montana.

History: County created Feb. 2, 1865, Bannack State. p528; boundaries established Nov. 20, 1867, L. 1867, p. 105: sec. 1, Cod. Stat. 1871, p. 428; Sec. 323, 5th Div. Rev. Stat 1879: Sec. 730, 5th Div. Comp. Stat. 1887; Flathead county created out of, Feb. 6, 1893, L. 1893, pp. 198-201; Teton county created from part of, Feb. 7, 1893, L. 1893, pp. 205-209; Granite county created from part of, March 2, 1893, L. 1893, pp. 212-217; Ravalli county created out of, Feb. 16, 1893, P. 212; Secs 4107, 4124, 4128, 4132, 4130, 4132, Pol. C. 1895; Sanders county created out of, Ch. 9, L. 1905; Secs. 2788, 2821, 2826, 2828, 2830, 2843, Rev. C. 1907; boundaries changed, Ch. 54, L. 1911; boundaries changed Ch. 43, L. 1913; Mineral county detached, Aug. 7, 1914; part of Powell county added, Feb. 27, 1915, Ch. 46, L. 1915; boundaries defined by Ch. 205, L. 1921; re-en. Sec. 4335, R.C.M. 1921; re-en. Sec. 4335, R.C.M. 1935; R.C.M. 1947, 16-232.

(MCA. 1993c)
## Appendix I - USGS Digital Line Graph Files Used for Baseline Layers in MSLACO

*(See Figure 3.2.1 for reference).*

<table>
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## Appendix J - Source of Local FSO Jurisdictional Boundary Data

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<th>FSO</th>
<th>Source of Data</th>
<th>Compilation Date</th>
<th>Notes</th>
</tr>
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<tbody>
<tr>
<td>Missoula FD</td>
<td>Missoula City Engineer’s Office; 1:12,000 scale blueline paper map.</td>
<td>1-22-92</td>
<td>Boundary is coincident with the Missoula City boundary. The most recent update had been done 1-22-92 by D. Jordan. Although there have been some recent changes to this map due to annexations, they are very minor and reflect a total area that is insignificant for this analysis.</td>
</tr>
<tr>
<td>Missoula RFD</td>
<td>District maps (paper), scale of 1:24,000.</td>
<td>6-92</td>
<td>All of the District lies within Missoula County.</td>
</tr>
<tr>
<td>Frenchtown RFD</td>
<td>Paper map from Missoula County Surveyor’s office. Scale unknown; used section/township lines as reference.</td>
<td>6-92</td>
<td>Of particular interest in this map was the boundary of the Petty Creek addition. The County Surveyor’s Office had drawn boundaries for this part of the District from a legal description of the properties involved. All of the District lies within Missoula County.</td>
</tr>
<tr>
<td>Clinton RFD</td>
<td>Missoula County Surveyor’s Office 1:60,000 scale blueline paper map.</td>
<td>9-90</td>
<td>The boundaries were checked against other maps and found to be accurate in regard to what was obtained from the original County map. All of the District lies within Missoula County.</td>
</tr>
<tr>
<td>East Missoula RFD</td>
<td>East Missoula RFD station map; Missoula County Surveyor’s Office 1:60,000 scale blueline paper map.</td>
<td>9-90</td>
<td>Boundaries were checked against Missoula RFD, Missoula FD, Clinton RFD, and DSL’s maps and found to be accurate in relation to the original blueline map. All of the district lies within Missoula County.</td>
</tr>
<tr>
<td>Arlee RFD</td>
<td>Missoula County Surveyor’s Office 1:60,000 scale blueline paper map.</td>
<td>9-90</td>
<td>The boundary for this District is predominantly coincident with the BIA boundary, and was found to be accurate in relation to the original County map. Much of the District lies outside of Missoula County (in Lake County).</td>
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<tr>
<td>Florence RFD</td>
<td>Florence RFD fire station map; information obtained by discussion of boundary locations with Chief Gordon Geiser and noting boundary locations on USFS 1:126,720 map.</td>
<td>7-93</td>
<td>Much of the District lies outside of Missoula County (in Ravalli County).</td>
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<tr>
<td>Seeley Lake RFD</td>
<td>Corrections from original blueline map were obtained from Asst. Chief Colin Moon.</td>
<td>5-92</td>
<td>All of the District lies within Missoula County.</td>
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<tr>
<td>Greenough-P FSA</td>
<td>Missoula County Elections Office (paper map and legal description).</td>
<td>7-93</td>
<td>This was a Volunteer Fire Company from 1991 - 1993. At that time, the boundaries were drawn and submitted to the County Elections Office. Boundaries used to delineate this new Fee Service Area were transferred from the paper map obtained from the Missoula County Elections Office. All of the Service Area lies within Missoula County.</td>
</tr>
<tr>
<td>Ovando RFD</td>
<td>Montana Dept. of State Lands records.</td>
<td>7-93</td>
<td>The District annexed a small portion of Missoula County, containing the Dept. of State Lands Clearwater Unit complex, in 1992. The boundary was added from DSL’s records. Most of the District lies in adjacent Powell County.</td>
</tr>
<tr>
<td>Swan Valley VFC</td>
<td>No jurisdictional boundaries.</td>
<td>Not mapped</td>
<td>Fire station located in Condon, Montana.</td>
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Appendix K - IFSL Fuel Models Used in the Study

The following descriptions of IFSL fuel models are excerpts from NWGC, 1981. Photos are from Anderson, 1982.

IFSL Fuel Model 1 - Short Grass
Fire spread is governed by the fine herbaceous fuels that have cured or are nearly cured. Very little, if any, shrubs or timber is present, generally less than one-third the area. Best fits grasslands that are not grazed, savannah types, stubble, grass with scattered shrubs, and grass-tundra or low tussock with grasses, mosses, and lichens. Surface fires can burn very rapidly.

IFSL Fuel Model 2 -- Timber (Grass and Understory)
Fire spread is primarily through fine, herbaceous fuels, either curing or dead. In addition, litter and dead-down stemwood from open shrub or timber overstory contributes to fire intensity. Shrub or tree cover is approximately one-third to two-thirds of the area. Best fits open pine/grassy understory, wiregrass/scrub oak associations, but can be used for timber/sagebrush associations, some pinyon-juniper stands, and southern clearcut slash. Surface fires can spread easily. Clumps of fuels that generate higher intensities may produce firebrands.

IFSL Fuel Model 5 -- Brush (2 feet)
Fire is generally carried in the surface fuels that are made up of litter cast by the shrubs and the grasses or forbs in the understory. Shrubs are generally not tall but have nearly total coverage of the area. Best fits the generally non-flammable shrubs such as laurel, salal, vine maple, alder, or mountain mahogany. Young green stands of chaparral, manzanita, and chamise qualify until deadwood is generated. Fires are generally of low intensity as surface fuel loads are young, with little dead, and the foliage contains little volatile materials.
**IFSL Fuel Model 8 -- Closed Timber Litter**

Closed canopy stands of healthy, short-needled conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly needles, leaves, and some twigs since little undergrowth is present. Representative conifer types are white pine, lodgepole pine, spruces, firs, and larch. Slow-burning surface fires with low flame heights are typical, although an occasional "jackpot" or heavy fuel concentration can cause flareups.

![Image of closed timber litter](image1)

**IFSL Fuel Model 9 -- Hardwood Litter**

Fire spread is primarily in surface litter such as concentrations of dead, dry leaves in fall or spring. Stands can be hardwoods, mixed hardwood/conifers, or long needle conifers. The oak/hickory types are best represented, but also covers other hardwoods and loosely compacted litter under long-needled conifers, such as ponderosa, Jeffrey and red pines or southern pine plantations. Also includes mixed hardwoods/white spruce type in Alaska when conditions are very dry. Fires run through the surface litter and possibly torch out trees, spot, and crown where concentrations of dead-down woody materials are present.

![Image of hardwood litter](image2)

**IFSL Fuel Model 10 -- Timber (Litter and Understory)**

Fire spreads through high loadings of dead, down woody fuels beneath over-mature timber stands. Shrub understory may be present. Much of the woody material is over 3 inches in diameter. Any forest type may be considered if heavy down materials are present; examples are insect or disease-ridden stands, over-mature situations with deadfall, and aged light thinning slash. Also used for settled thinning or partial cut conifer slash with needles fallen. Torching of individual trees and spotting is more frequent, and fire intensity is higher in this model than model 8 or 9, thereby leading to potential fire control difficulties.

![Image of timber litter and understory](image3)
Non-wildland and non-fuel types

Some parts of Missoula County and the Rattlesnake Valley do not fall into any of the IFSL fuel models due to a lack of flammable vegetation. The following "fuel" classifications were used for areas that are either devoid of wildland fuels, or whose vegetation does not generally support wildland fires. Numbers assigned to these fuel classifications are arbitrary, but are well outside the range of the standard IFSL fuel models (1-13).

00 -- Water
This classification was used to represent any areas covered by a continuous, open surface of water year-round. It includes lakes, rivers, and perennial creeks. This fuel type is considered non-flammable and was assigned a flame length and rate-of-spread value of zero in every case.

99 -- Rock, Dirt, and Snow
This classification was used to represent any areas devoid of vegetation or down-dead fuel. Examples include road grades, gravel pits, and high-elevation areas consisting primarily of rock and snow fields. This fuel type is also considered to be non-flammable and was assigned a flame length and rate-of-spread value of zero in every case.

98 -- Urban and Suburban Areas
This "pseudo-fuel" type was used to represent areas where natural vegetation has been removed and replaced with other, less flammable vegetation types. Examples are landscaped yards and public parks. Although true "wildland" fires are uncommon in these areas, fire service organization records indicate that vegetation fires occasionally do occur. However, they are usually limited to small patches of weeds or isolated clumps of ornamental vegetation (such as juniper bushes). These areas were assigned a standard flame length of 0.1 ft.

Fuel models in MSLCAO dataset, and area represented by each.

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<th>Fuel Model Number</th>
<th>Description</th>
<th>Percent of Area</th>
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<td>Short Grass</td>
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<tr>
<td>2</td>
<td>Grass in open pine, sagebrush</td>
<td>24.85</td>
</tr>
<tr>
<td>5</td>
<td>Low shrubs, with or without overstory</td>
<td>8.73</td>
</tr>
<tr>
<td>8</td>
<td>Closed timber litter</td>
<td>1.16</td>
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<tr>
<td>9</td>
<td>Hardwood litter</td>
<td>0.95</td>
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<tr>
<td>10</td>
<td>Timber (litter and understory)</td>
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<td>&quot;00&quot;</td>
<td>Water</td>
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<tr>
<td>&quot;99&quot;</td>
<td>Rock, dirt, snow</td>
<td>1.25</td>
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<tr>
<td>&quot;98&quot;</td>
<td>Urban/suburban</td>
<td>0.79</td>
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Appendix L - Missoula County Land Cover Classes

Appendix L. Missoula County land cover classes for the vegetation layer derived from classified LANDSAT TM data. This appendix was transcribed from a one-page information sheet written by Dr. Zhenkui Ma for the County of Missoula.

Missoula County Land Cover Classes

1. Urban lands
2. Agricultural Lands
3. Rangelands
   34. Rangeland or possible low density forest lands.
4. Forest lands
   40. Low density forest land with broadleaf shrubs
   41. Broadleaf forest
   42. Needleleaf forest
   43. Mixed forest
   44. Low density forest land without broadleaf shrubs
5. Water
   51. Streams
   52. Lakes
6. Wetlands
   61. Forest-dominated riparian lands
   62. Shrub-dominated riparian lands
   63. Graminoid or forb-dominated riparian lands
7. Barren lands
8. Tundra
9. Snow

NOTE: The TM data alone were not sufficient to accurately map the wetland cover types. The occurrence of these three cover types was predicted according to a model which uses the TM data, along with a Digital Elevation Model (DEM), and hydrological data. Model rules were developed in close consultation with Pat O’Herren. First, a potential riparian buffer zone around all lakes, rivers, and perennial streams was identified with a 90 meter buffer on each side of these features using the USGS digital line graph data representing hydrology at 1:100000 scale. A 10 meter elevational limit above these water levels was used to refine the riparian zone within the 180 meter wide strip. Hence, the width of the mapped riparian zone varied according to topography at different locations to match more closely real-world conditions. This modified riparian zone was next overlaid with the land cover layer. Forest cover types in the zone were identified as forest-dominated riparian, shrub cover types in the zone were identified as shrub-dominated riparian, and grass or forb types in the zone were identified as graminoid and forb dominated riparian.
Appendix M. Description of the classification of LANDSAT TM imagery used to derive the land cover classes used in this project. This description was written by Dr. Ma for the County of Missoula.

Missoula County Land Cover Map

Prepared by:

Dr. Zhenkui Ma
Montana Cooperative Wildlife Research Unit
University of Montana
Missoula, MT 59812

December 1993

Land cover for Missoula County was mapped according to a two stage, digital process that integrated LANDSAT Thematic Mapper (TM) data with ancillary biophysical data in a computerized geographic information system (GIS). In the first stage, 30 m² pixels from a July 21, 1991 TM image were assigned to spectral classes through an unsupervised classification of TM channels 3, 4, and 5. The classified image was regrouped to reduce the number of classes, and then smoothed by a 3*3 window filter to remove the “salt and pepper” pixels. Resulting pixel groups that represented areas smaller than 2.5 acres (i.e., fewer than 11 pixels) were merged with neighbors according to specific rules which allowed for linear features, like rivers and roads, to be kept at the original 30 m² resolution.

In the second stage, the merger output file was converted into an ARC/INFO grid file, and an attribute table was built. For each region (contiguous group of pixels representing the same spectral class), the attribute file contained mean values for all seven spectral channels (TM data) along with elevation, aspect, and slope. Training regions for different land cover classes were then identified, and the information in the attribute file for the training regions was used to conduct a supervised classification of all other regions. The land cover for Missoula County is described according to the classes described on the following page.
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